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MAN AS A SOURCE OF MECHANICAL POWER

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It is deduced from the published literature that the usable external power output of the body is limited in the following manner for the reasons stated :

(1) In single movements (of duration less than 1 sec) to less than 6 h.p. ; by the intrinsic power production of muscle, and by the difficulty of coupling a large mass of muscle to a suitably matched load.

(2) In brief bouts of exercise (0·1–5 min) to 2–0·5 h.p. ; by the availability in the muscles of stores of chemical substances that can yield energy by hydrolysis.

(3) In steady-state work (5 min to 150 min or more) to 0·5–0·4 h.p. ; by the ability of the body to absorb and transport oxygen.

(4) In long-term work, lasting all day, to perhaps 0·2 h.p. ; by wear and tear of muscles, the need to eat, etc.

All these figures refer to champion athletes ; ordinary healthy individuals can produce less than 70–80 per cent as much power.

§ 1. Introduction

Until about two centuries ago almost all the world's work was done by muscle-power, and much of the muscle was human. This paper sets out to examine the properties of man considered purely as a source of mechanical power. Knowledge of these properties is of interest both in athletics and in the design of man-driven machines. The study was undertaken in order to find out theoretically whether it is possible for man to fly by his own efforts : probably it is (Shenstone 1956, Nonweiler 1958 b, Wilkie 1959).

We all know that we can work harder for a short period of time than for a long one, but there are few systematic studies (e.g. Ursinus 1936, Unna 1946, Krendell 1958, Nonweiler 1958 a) of the exact way in which power output diminishes as the duration of exercise increases. Extensive physiological studies have been made on running, but in this form of exercise little external work is done, so that results are of only indirect use for the present purpose.

Observations on various types of exercise, from many sources, are plotted in Fig. 2 : the best performances at each duration have been extracted and plotted in Fig. 1. Note that, in both cases, the horizontal scale does *not* represent the time from the beginning of the exercise, but the duration for which a given constant output can be maintained ; a linear scale is used in Fig. 1 and a logarithmic one in Fig. 2. For a short period of time very heavy work can be performed, but the total power output diminishes steeply the longer the total duration of exercise. However, when the duration of working is greater than about 5 min, the rate of working diminishes only very slowly with increasing duration of exercise. In order to understand these observations, it is necessary to know something of the physiology of muscular exercise.

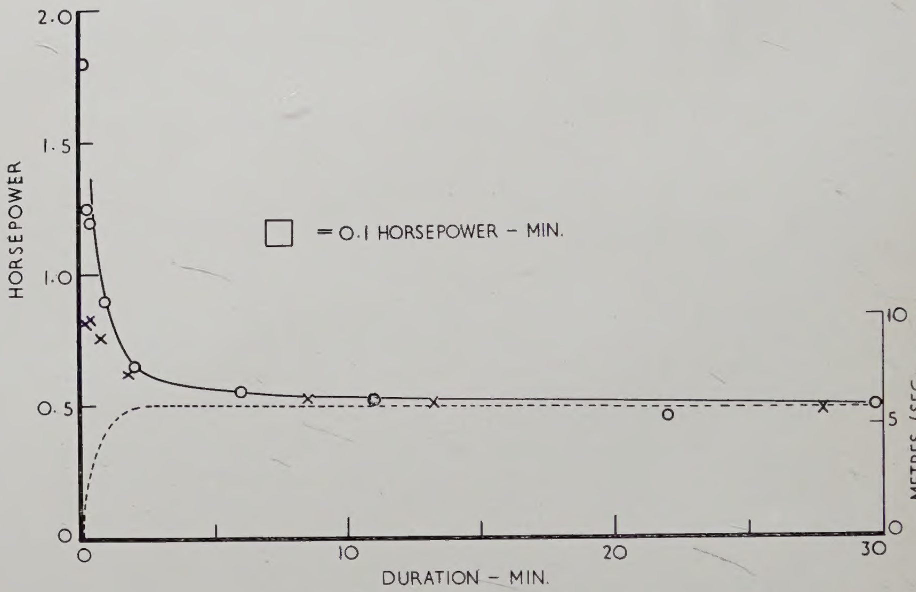

Figure 1. Left-hand ordinate ; circles, maximal external mechanical power produced by champion athletes, data extracted from Fig. 2.

Right-hand ordinate ; crosses, running speed, world records (Guinness 1956).

Abscissa ; total duration of exercise (*not* time elapsed since the beginning of exercise).

The broken line shows the energy available from oxidative processes. To this is added 0·58 h.p. min of work from anaerobic (hydrolytic) sources, to give the theoretical curve, full line.

N.B. 1 h.p. = 0·746 kw = 76 kg-wt metres sec^{-1}.

§ 2. The Physiology of Muscular Exercise

The function of muscles is to transform chemical energy into mechanical energy. All the chemical processes take place at constant temperature, that is, their energy does not appear at an intermediate stage as heat. For this reason muscle is quite unlike a heat engine. Though the chemical processes involved are very complicated, muscle achieves an efficiency (= work output/chemical energy used) of 20–25 per cent under favourable conditions : the chemical energy comes ultimately from the oxidation of foodstuffs, most probably of the carbohydrate, glycogen, and of fatty acids, to carbon dioxide and water.

From the long-term point of view energy production by muscle thus depends on an adequate supply of oxygen, which must be absorbed at the lungs and transported by the blood-stream to the active muscles. Both lungs and blood-stream have a limited capacity, which in turn sets a limit to the steady-state energy production. Fit young men can absorb up to 4 litres of oxygen per minute (Åstrand 1952, Slonim *et al.* 1957) ; the maximum absorption that has been recorded is 5·4 litres/min, by an Olympic athlete. Since 1 litre of oxygen yields about 0·1 h.p. min of mechanical work under optimal conditions, the steady-state power output must be limited to 0·4–0·54 h.p., depending on whether we are considering fit ordinary men or champion athletes. This prediction correlates well with direct measurements of mechanical power output, see Figs. 1 and 2.

2.1. *Chemical Considerations*

Although the ultimate source of muscular energy is oxidation, the immediate source of energy is the hydrolysis of various compounds, such as adenosine triphosphate, creatine phosphate, and, when oxygen is lacking, the hydrolysis of glycogen to lactic acid (see, e.g. Needham 1956). The *rate* of these hydrolytic reactions is not limited by the supply of reactants from outside the muscle, and it may therefore be very high, though the *total amount* of energy available is limited by the amounts of such chemicals stored in the muscle. As shown in Fig. 1 the experimental measurements of maximal work-production (circles) satisfactorily fit a theoretical curve (full line) constructed on the assumptions : (1) that there is a steady oxidative energy production of 0·5 h.p. falling to 0·475 h.p. after 25 min as a result of long-term fatigue (broken line) ; (2) that to this is added a ‘ lump-sum ’ of mechanical work derived from hydrolytic reactions. This amounts in practice to about 0·6 h.p. min, which can be released over a long or short period, according to need.

The theoretical calculation is made slightly more complex by the fact that oxygen consumption provoked by exercise does not rise instantly to its full value as soon as exercise begins. It rises instead with a roughly exponential time-course (half-time approximately 30–40 sec) (Hill 1927). Thus during a short bout of maximal exercise a disproportionate amount of energy has to come from anaerobic processes (Sargent 1926). Possibly the resulting metabolites are initially responsible for stimulating the increase in oxygen intake, so this increase does not occur until the metabolites have accumulated to some degree.

The experimental points in Figs. 1 and 2 both refer to a steady rate of power production, maintained for the duration indicated. A theoretical analysis into oxidative and hydrolytic components makes it possible to forecast the limits of performance if the task set involves non-uniform power production ; in this case, the hydrolytic ‘ lump-sum ’ must be distributed in an appropriate way as a function of time.

Of course, the stores of hydrolysable chemicals must be replenished after the exercise is over, the energy needed being obtained from additional oxidation : thus the ‘ oxygen debt ’ accumulated during exercise is paid off during recovery. The maximum oxygen debt that can be accumulated is about 20 litres. This might be expected to yield about 2 h.p. min, but we have seen in practice that only a third of this (0·6 h.p. min) is actually obtained as external mechanical work. The reason for the inefficient utilization of the oxygen debt is not altogether clear.

2.2. *Mechanical Considerations*

The speed with which a muscle shortens depends on the force to be overcome : the larger the force, the slower the shortening, and vice versa. No work is done if the force is zero, or if the force is so great that the speed is zero ; though chemical energy will be consumed almost as usual. In order to achieve an optimal conversion efficiency of 20–25 per cent, force and speed of movement must be suitably matched to one another. It so happens that the optimum occurs when the force has about one-half, and the speed of movement has about one-quarter of their respective maximum values (Hill 1939). For the

greatest power output, regardless of economy, the force should be somewhat less and the speed somewhat greater. With a machine, such as a bicycle, it is usually possible to adjust the gearing so that the load is matched to the muscles ; but in many athletic pursuits this is not the case. Some examples will be discussed later.

It should also be noted that the conversion from chemical to mechanical energy in muscle is a one-way process. Animals are obliged to employ reciprocating movements, not rotations, so the kinetic energy of their limbs is continually altering. Energy given to accelerate a limb will inevitably be wasted unless there is a mechanism to decelerate the limb again and store the energy. If the movement has to be checked by the contraction of antagonistic muscles, these will use up yet more energy, not gain it (Abbott *et al.* 1952).

§ 3. Experimental Data

In this presentation of the data collected from many sources an attempt has been made to distinguish between the results obtained from different types of exercise, and also to distinguish champion athletes from healthy non-athletes. This last distinction may seem somewhat arbitrary, but when it is made, the experimental points fall into two fairly well-defined sets. The champion athletes (double circles in Fig. 2) can develop 20–30 per cent more power than healthy normal men can, for a given type of exercise.

Running (Fig. 2; triangles) is not a good way of producing external mechanical work. In sprinting at 7 m/sec—a speed which can be kept up for perhaps 30 sec—only 0·16 h.p. appears as external work, in overcoming air resistance. At the same time an estimated 2·4 h.p. is dissipated internally; 0·6–0·7 h.p. in raising and lowering the centre of gravity, and 1·7 h.p. in changing the kinetic energy of the limbs (Fenn 1930). Sprinting against an artificial resistance has yielded 0·31 h.p. of external power (Best and Partridge 1928), but this must also be only a small fraction of the actual mechanical power developed. However, the metabolic changes resulting from running have been extensively studied (e.g. Sargent 1926, Hill 1927, Bannister 1956). Fast running has been shown to be very uneconomical; a large increase in energy expended leads to only a small increase in speed.

The same effect can be seen in Fig. 1 (crosses). At speeds less than about 6 m/sec, running speed decreases in exactly the same way with increasing duration of exercise as does the working ability of the body. But in short bouts of exercise, of duration less than 1 min, running speed falls off compared with the ability to perform external work (compare crosses and circles in Fig. 1).

The triangles in Fig. 2 all represent work done while running uphill. Normally this activity merely leads to an increase in the potential energy of the body, but it could, in theory at least, be made available by using a treadmill.

Rowing, using a sliding seat (Fig. 2; upright crosses) is an effective method of producing external mechanical work so long as the duration is more than two or three minutes. For shorter bouts it is very uneconomical because of the disproportionate wastage of energy from acceleration and deceleration of the whole body that results when this type of movement is made at high frequency (Ursinus 1936). The advantage that might have been expected theoretically from the use of a larger muscle-mass is thus not obtained in practice.

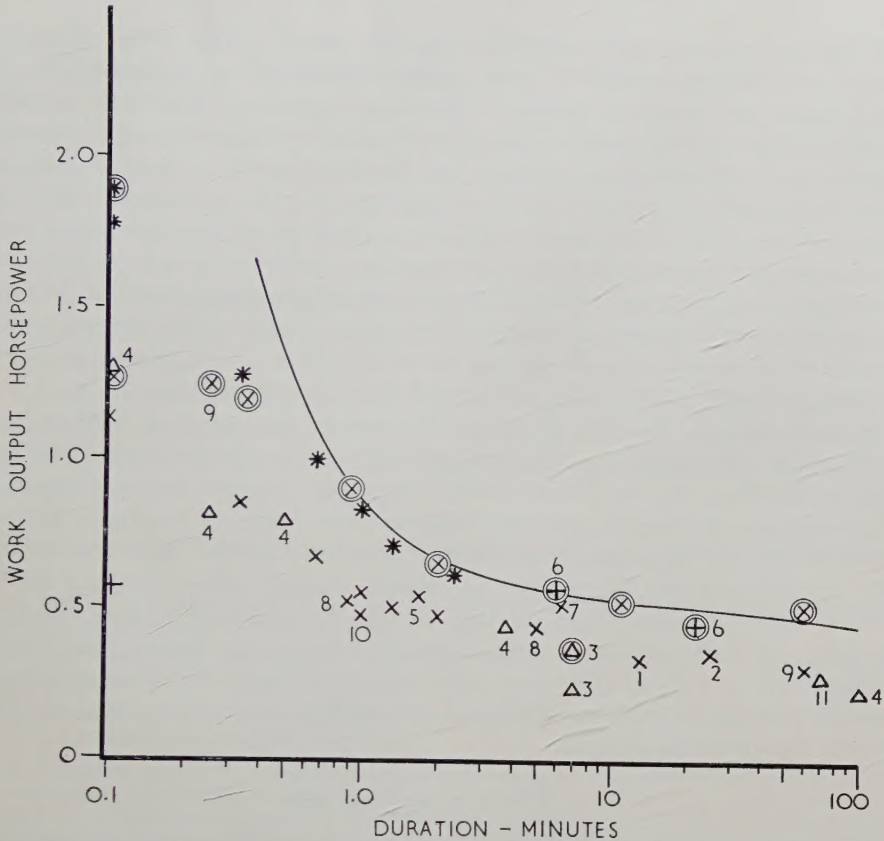

Figure 2. Maximal output of external mechanical power (h.p., linear scale) plotted against total duration of exercise (min, logarithmic scale). The logarithmic scale has been used to display the experimental points clearly.

Δ running uphill ;

+ rowing ;

× cycling ;

* cycling and turning hand crank ;

◎ added to a symbol means that the performance was by a champion athlete.

Full line is the theoretical curve shown in Fig. 1.

The numeral indicates the source from which the experimental point was derived. Points without numerals : champion cyclists, ⊗ Nonweiler 1958 a ; ordinary cyclists, × also ordinary cyclist performing hand-cranking in addition, * (Ursinus 1937).

1, Abbott *et al.* ; 2, Asmussen ; 3, Bannister *et al.* ; 4, Benedict *et al.* ; 5, Bonjer 6, Henderson *et al.* ; 7, Karpovich *et al.* ; 8, Nielsen *et al.* ; 9, Raleigh ; 10, Tuttle ; 11, Unna.

Pedal-cycling (Fig. 2; diagonal crosses) can be adapted to various durations of maximal effort. The mechanical system involved is simple and lends itself to the free use of the power obtained: gearing can be readily adjusted; and maximum use can be made of the kinetic energy of the moving limbs. In cycling the full steady-state power production of the body can be developed. Thus the muscle-mass of the legs is evidently more than large enough to utilize all the oxygen that can be absorbed. The maximum rate of pedalling, under no-load conditions, e.g. in roller-racing, is about 180 r.p.m., the optimum for greatest efficiency is about 60 r.p.m., and the speed used in cycling contests (where economy may have to be sacrificed to output) varies from 60–120 r.p.m.

Pedal-cycling with hand-cranking (Fig. 2; stars). The total amount of energy immediately available from hydrolytic reactions is limited by the initial size of the chemical stores in the *active* muscles. Therefore, maximal use of hydrolytic energy sources can be made only by employing and exhausting as large a mass of muscle as possible. So, for short bouts of exercise, the more muscle employed the greater the power developed. Accordingly, it has been found (Ursinus 1936, 1937) that simultaneous cycling and hand-cranking yields about 50 per cent more power than cycling alone, but only for a short time; the advantage is rather small after 5–10 min, when the power output becomes limited by oxygen supply rather than by muscle-mass. Four different types of machine for combined arm and leg movement were thoroughly investigated by Ursinus (1936, 1937), who concluded that simple rotation of a 17·5 cm crank by hand and foot was the most effective arrangement, as well as being mechanically the simplest. He also established the optimal speed for each duration of effort; the best phase relation between arm and leg; and the scope and limitations of various postures, ranging from lying on the back, through normal sitting, to lying face downwards. Most of Ursinus' experiments were made on a subject who, though not an athlete, was yet able to produce for two minutes a power output equal to that of the best athletic cyclists using the legs only. If cycling athletes were to benefit to a similar degree from the use of their arms as well as their legs, this would substantially raise the experimental points at the extreme left-hand side of Figs. 1 and 2, so that they fell closer to the theoretical curve.

3.1. *Efforts of short duration*

The points plotted at 0·1 min in Fig. 2 are not strictly comparable with one another. They represent maximum peak outputs whose short but uncertain durations depended on many factors—for example, on the inertia of the apparatus. The bout of exercise will in each case have consisted of a number of repeated movements. It is of interest to consider what may be the power output of the body during a *single* movement, occupying a second or less. In this case the power is limited only by the mass of muscle that can be brought to bear effectively, for fatigue can hardly arise within such a short time. A theoretical upper limit of about 11 h.p. is set by two facts: that the body is about 45 per cent muscle; and that human muscle can develop about 0·3 h.p. per kilogram when it is shortening against a matched load (Wilkie 1950). The full amount of power could only be extracted, of course, if it were possible to connect every muscle in the body to a suitable load, then to throw them all into contraction at once. The mere fact that muscles are almost all arranged in the body in antagonistic pairs may be expected to reduce the theoretical limit for any practicable movement to perhaps 5 or 6 h.p.

Actual measurements of the power output of the body during a single movement are rare. Gertz (1929) calculated the work done by a sprinter in accelerating himself at the beginning of a race, and arrived at an estimate of 3–4·5 h.p. maintained for about a second. Similar calculations have been made from cine-films of athletes performing a standing jump off both feet (3 h.p. for 0·2 sec) and weight-lifting (2 h.p. for 0·6 sec: Fletcher *et al.* 1958 and unpublished observations). In neither of these examples is the load at all well matched to the muscles so as to exploit to the full their intrinsic *force: velocity* relationship,

see p. (3). In jumping, the shortening velocity of the muscle rises from zero at the beginning to a high value at take-off, so it cannot remain for long at its optimum. In weight-lifting, the whole competition is to lift the heaviest possible weight, so that the tension in the muscle must be near to its isometric value. The *force: velocity* curve indicates that the resulting speed of shortening, and power output, must both be small. Even when the subject is asked to lift a lighter weight, he is unable to move to a more favourable part of his *force: velocity* curve, for the movement can not, apparently, be made at a higher speed without risk of injury. Consequently the movement is made at the same speed, using fewer active muscle fibres, and the power output is even lower than before.

In order to investigate the peak power output of the body in more detail, it would be necessary to construct a machine for the specific purpose of absorbing the work from arms, torso and legs at optimal speed; it seems that no existing athletic task is suitable.

D'une revision de la littérature, on tire les conclusions suivantes sur la puissance mécanique humaine :

(1) Lors de mouvements isolés, elle est limitée à moins de 6 c.v. par la puissance propre du muscle et par la difficulté de coupler chaque muscle à un poids approprié.

(2) Lors d'efforts de brève durée (0,1–5 min), elle est limitée à 2–0,5 c.v. par les ressources chimiques internes des muscles.

(3) Pendant le travail à ' steady state ' (5–150 min ou plus), elle est limitée à 0,5–0,4 c.v. par les mécanismes de transport d'oxygène.

(4) Lors d'un travail de longue durée (toute la journée), la puissance, reduite par la ' fatigue ' à longue terme, est estimée à 0,2 c.v.

Tous ces chiffres se rapportent à des athlètes exceptionnels. Les individues sains mais non entrainés ne peuvent fournier que le 70 pour cent à 80 pour cent des puissances indiqués.

Aus der publizierten Literatur wird abgeleitet und begründet, dass die nutzbare mechanische Leistung des Körpers folgendermassen begrenzt ist:

(1) Für eine einzige Bewegung (von weniger als 1 sec Dauer) auf weniger als 6 PS, durch die dem Muskel eigene Leistungsfähigkeit und durch die Schwierigkeit, einer grossen Muskelmasse eine gut angepasste Last zuzuordnen.

(2) Für kurze Arbeitsabschnitte (0,1–5 min) auf 2–0,5 PS, durch den verfügbaren Vorrat chemischer hydrolysierbarer Substanzen in den Muskeln.

3. Für ' steady state '—Arbeit (5 min bis 150 min und mehr) auf 0,5–0,4 PS, durch die Fähigkeit des Körpers, Sauerstoff aufzunehmen und zu transportieren.

(4) Für langdauernde Arbeit (ganztägig) auf etwa 0,2 PS, durch Abnutzung und Erschöpfung der Muskeln, durch die Notwendigkeit zu essen, etc.

Alle diese Zahlen betreffen Spitzen–Sportler; normale, gesunde Personen erzeugen weniger als 70–80 prozent dieser Leistungen.

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EVALUATION OF A SUBMAXIMAL TEST FOR ESTIMATING PHYSICAL WORK CAPACITY

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The reliability and validity of the Bruce Physical Fitness Index as a means of evaluating the physical fitness of athletes and normal healthy non-athletes are evaluated experimentally. The Index does not correlate well with performance in cross-country running, and is less sensitive to changes in cardio-respiratory fitness than is oxygen consumption alone. Large individual variations are found on test-retest of normal subjects. Participants in different sports show differences which are too great to permit of their being grouped together as 'athletes'. Possible reasons for the failure of the Index to be more discriminatory are discussed.

§ 1. Introduction

Clinical exercise-tolerance tests and their relation to fitness for athletic, industrial, and military purposes have been reviewed and evaluated by Harris (1958). He notes that Bruce and his collaborators have developed a Physical Fitness Index (PFI) which they believe to be "helpful in the assessment of cardiac patients for operation", but he passes no judgment on the index other than to comment that it seems "doubtful whether the PFI is fundamentally more reliable than its individual components". Bruce *et al.* (1953) report that "The exercise tolerance test has been useful in evaluating the patient's disability due to mitral stenosis and changes that occur in the natural history of the disease", and indicate that improvements in endurance as a result of preoperative treatment are accompanied by improved scores in the PFI. However, it does not appear that the value of this test in estimating the physical work capacity of athletes and normal healthy non-athletes has been established.

A valid and reliable test of this sort is badly needed. Wahlund (1948) contends that any physical fitness test must satisfy seven criteria:

1. A large number of muscles must be involved.
2. Sufficiently heavy loads must be used to make it possible to estimate the maximal steady-state level of the subject.
3. There must be a possibility for most of the subjects to attain a steady state during moderate loads.
4. The working time must not be so long as to cause carbohydrate exhaustion and hydrostatic changes of the blood distribution.
5. The test should not be one in which some individuals may have a much better mechanical efficiency than others.
6. The work load must be standardized and controlled.
7. For determination of the working intensity, oxygen consumption measurements must be made.

Theoretically such a test might (1) measure an individual's capacity to perform maximal work, or (2) measure his response to a fixed amount of moderate work. Indices of the first type, such as the Harvard Step Test, have not been found to be of great use. It is almost self-evident that they are too severe for

use with patients. In the experience of the authors only rarely are healthy, normal, untrained individuals capable of establishing a steady state in this test; relatively few untrained subjects continue the Harvard Step Test over 2·5min. Tests of this kind, therefore, violate Wahlund's third criterion. It is less generally realized that coaches and trainers will seldom permit athletes under their charge to participate in tests of this character, as they have learned from bitter experience that the resulting fatigue and muscular soreness may seriously impede the athlete's training programme.

§ 2. The Bruce Physical Fitness Index

Bruce *et al.* (1951) present the PFI as " an improvement of the formula employed at the Harvard Fatigue Laboratory for evaluating performance in athletes at exhausting work-loads ". The exercise consists of walking on a motor driven treadmill with a 10 per cent grade at the rate of 1·73 miles per hour for a maximum of ten minutes. The Physical Fitness Index is computed by the formula

$$\mathrm{PFI} = \frac{E \,.\, R \,.\, K}{C}$$

where E = Duration of exercise in minutes; R = Average respiratory efficiency (difference in oxygen concentration between inspired and expired air); $K = 100$; C = Cumulative heart rate for the first three minutes of recovery.

The test scores are evaluated upon a continuum on which 13 is abnormally low, 19 is said to be characteristic of the sedentary individual, 23 of the average, and 26 of the athlete. The underlying rationale is that in such a test the intensity of the stress should be roughly comparable with ordinary daily levels of physical activity, the ability to work is related to the amount of oxygen which is available to the tissues, and the index figures are related to the severity of anoxia at the tissue level.

It is evident that walking on a treadmill operating under the prescribed conditions is a submaximal load for any normal individual and the PFI thus meets the objection to the Harvard Step Test. Unfortunately the derivation of the continuum and meaning of the scores are not equally clear. The primary purpose of tests of this kind is to predict how the individual will perform in a practical situation. Fitness is measured only by an individual's ability to perform work and to recover therefrom, and, since fitness is more or less specific to the task, it cannot be assumed that any one test will measure fitness for all types of work with equal accuracy. It is necessary, therefore, to determine the correlation of a proposed test with a number of different tasks before its value in predicting how the subject will fare in them can be determined. A test which has been found useful in the evaluation of mitral stenosis patients may or may not prove useful in the evaluation of non-patients.

In one study the originators of this test (Bruce *et al.* 1951) speak of measuring 75 normal controls and 184 ambulatory patients; in another (Bruce *et al.* 1952) they refer to seven normal male subjects and two patients. Presumably the scores on the continuum represent means obtained from observations of these individuals, but in the papers which have come to the writers' attention there is no description of the way in which such scores were determined. The authors do not mention having tested athletes of any kind, they do not define what they

mean by this term, and the derivation of the score of 26 as characteristic of athletes is obscure.

No data are available on training effects, variations in daily score, correlations with routine anthropometric measurements, or intercorrelations of the various parts of the test. Although it is stated (Bruce *et al.* 1953) that the test shows a high degree of reproducibility with mitral stenosis patients, as judged by test-retest scores at intervals of 0 to 24 days between the two tests, the reliability of a certain instrument applies only to a certain population under certain conditions and this finding cannot be extended to include non-mitral stenosis patients. While the PFI is presented as " an improvement of the formula " for the Harvard Step Test Recovery Index, when the two tests were administered to 20 normal healthy adult male subjects, the scores correlated $r=0{\cdot}236$, which is not statistically significant and which indicates that either the tests do not measure identical items to the same extent or that different items are measured by each (Rasch and Pierson 1959).

It was the purpose of this investigation to evaluate the reliability and validity of the Bruce PFI when employed in the testing of athletes and normal healthy non-athletes.

Procedure. The Bruce PFI was determined for four groups of subjects as follows:

Group 1 consisted of 26 healthy adult male students from the College of Osteopathic Physicians and Surgeons. The subjects were tested on a single occasion to check the continuum score given as characteristic of the average individual.

Group 2 consisted of 11 volunteers from a high school cross-country team*. These subjects were tested on a single occasion near the end of the season, when they were presumably in an excellent state of physical fitness for cross-country running and their times for the event were a matter of record.

Group 3 consisted of ten volunteers from a high school and a college football team. These subjects were tested on a single occasion just after the conclusion of the football season, when they were presumably in an excellent state of fitness for playing football.

Group 4 consisted of six healthy adult male students from the College of Osteopathic Physicians and Surgeons. These were selected to give a wide distribution of body type and contain 1 ectomorph, 1 ecto-mesomorph, 1 mesomorph, 2 meso-endomorphs, and 1 endomorph. These subjects were tested once a day, four days a week, for six consecutive weeks. Each week the time of day of testing was changed in order to determine the effect of meals, daily fatigue, and similar factors. During one week the subject ingested a diet high in carbohydrates; during another week he ingested a diet high in protein, to determine whether the specific dynamic action of various foods affected the scores.

§ 3. Results and Discussion

In all tests the difference in oxygen concentration between inspired and expired air was measured by use of an Arnold O. Beckman Model C Oxygen

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Analyser. Simultaneously the total oxygen consumption was recorded by means of an Arnold O. Beckman Model F Oxygen Analyser. Heart rate was recorded by use of a Burdick Type EK-2 Electrocardiograph and an Electro-Medical Engineering heart count recorder.

Data obtained from the first three groups of subjects are given in Table 1; those obtained from the fourth group are given in Table 2. Intercorrelations of physiological and anthropometric data are given in Table 3.

Table 1. Bruce PFI scores for non-athletes and for athletes

Subjects	Number	Range	Mean	Standard deviation	Median
Normal adult males	26	18	22·8	4·4	21·5
Cross-country runners	11	16	31·8	4·4	31·5
Football players	10	16	26·5	4·5	25·5

Table 2. Bruce PFI and O_2 consumption scores for normal male subjects

Subject	Bruce PFI		O_2 consumption ml per M^2 body surface area per min	
	Mean	S.D.	Mean	S.D.
S	19·3	2·5	471·2	57·7
M	18·3	2·6	522·7	53·6
K	27·2	2·7	518·0	62·8
C	24·9	3·8	512·8	66·8
Y	26·0	4·7	496·0	65·6
G	17·8	2·4	604·6	82·3
Mean	22·2	3·1	522·6	64·8

The mean of 22·8 for Group 1 (normal untrained subjects) is practically identical with the figure of 23 set on the continuum as characteristic of the average individual. However, it will be observed that the scores range from 17 to 35, with a standard deviation of 4·4. Bruce *et al.* (1949) accept the standard statistical convention that two standard deviations above and below the mean establish the limits of normality which may be expected on the basis of random sampling, but if two standard deviations are applied to the mean of these subjects, the resulting ‘ normal ’ range is 14–32, which exceeds the upper limits of the continuum and is almost abnormally low at the opposite end. The median for the group was 21·5, which is somewhat lower than the assumed mean given by Bruce *et al.*, and indicates that the data are somewhat skewed in favour of lower scores.

The mean score of 32 for Group 2, the cross-country runners, is beyond the range of the continuum. The standard deviation of 4·4 gives a ‘ normal ’ range of 16 to 31·8, which indicates that some trained cross-country runners might be expected to attain a score below that of sedentary individuals.

Table 3. Intercorrelations of physiological and anthropometric data

	Cross-country performance	Bruce PFI	Resting heart rate (1 min)	Post-exercise heart rate (3 min)	'Average respiratory efficiency'	Ponderal index	Reciprocal ponderal index	Body surface area	Oxygen volume per M² BSA	Lean body mass	Height	Weight
Cross-country performance		0·47	0·32	0·52	−0·25	−0·48	0·37	−0·12	−0·36	−0·18	0·05	−0·15
Bruce PFI	0·47		−0·60	−0·74*	0·28	0·37	−0·29	0·29	0·54	0·36	0·21	0·31
Resting heart rate (1 min)	0·32	−0·60		0·90*	0·44	−0·15	0·13	0·40	−0·44	0·33	0·46	0·35
Post-exercise heart rate (3 min)	0·52	−0·74*	0·90*		0·09	−0·14	0·12	0·33	−0·36	0·55	0·41	0·19
'Ave. respiratory efficiency'	−0·25	0·28	0·44	0·09		0·73*	−0·58	0·84*	0·17	0·84*	0·69	0·91*
Ponderal index	−0·48	0·37	−0·15	−0·14	0·73*			0·36	0·44	0·44		
Reciprocal ponderal index	0·37	−0·29	0·13	0·12	−0·58			−0·26	−0·35	−0·33		
Body surface area	−0·12	0·29	0·40	0·33	0·84*	0·36	−0·26			0·16		
Oxygen volume per M² BSA	−0·36	0·54	−0·44	−0·36	0·17	0·44	−0·35			0·13	−0·08	0·07
Lean body mass	−0·18	0·36	0·33	0·55	0·84	0·44	−0·33	0·16	0·13			
Height	0·05	0·21	0·46	0·41	0·69				−0·08			0·64
Weight	−0·15	0·31	0·35	0·19	0·91				0·07		0·64	

* $r = 0{\cdot}71$ is statistically significant.

The most recent time for the cross-country run was correlated with the runner's Bruce PFI, giving $r = 0{\cdot}47$, which was not statistically significant. This is confirmed by the fact that the runner with the best time made the highest score in the Bruce PFI: 40; but the runner with the worst time made the second highest score: 37. The post-exercise heart count correlated $r = 0{\cdot}52$ with performance, an indication that inclusion of the ' average respiratory efficiency ' in the Bruce PFI test actually reduces the predictive value of the test.

The mean score for Group 3, the football players, was 26·5 with a standard deviation of 4·5. Again the mean exceeds the upper limits of the continuum, while the lower limits of the ' normal ' population of football players might be expected to fall below that of sedentary individuals.

The results of the analysis of variance ($F = 43{\cdot}9$) indicate that the three groups are not from a homogeneous population. A significant difference in F may result from any one of three causes: (1) differences in mean scores, (2) differences in variances, or (3) both. In the present study the significant F may be attributed to differences in the mean scores. It is, therefore, erroneous to lump both cross-country runners and football players under a single classification of ' athlete ' and expect that a single physical fitness index will describe both of these non-homogeneous groups.

When the data collected in the longitudinal study conducted with Group 4 were subjected to the analysis of variance it was found that there were no significant differences which could be attributed to the time of day and diet ($F = 2{\cdot}5$), day of the week ($F = 1{\cdot}4$), or week of testing ($F = 1{\cdot}1$). No training effect was evident in the physical fitness index ($F = 1{\cdot}1$), the O_2 consumption ($F = 1{\cdot}3$), the heart rate ($F = 0{\cdot}3$), or the average respiratory efficiency ($F = 2{\cdot}4$). It is apparent that the exercise required by the Bruce PFI is not sufficiently intense, when performed only once a day, to produce the circulatory-respiratory changes customarily associated with athletic training. This suggests that the difficulties encountered with this test may be due to its failure to meet Wahlund's second criterion.

The variability of the mean score in the Bruce PFI for each individual ranges from 2·5 to 4·7, indicating that the least which could be expected would be an individual range of 10 points. Thus, a given individual could vary from sedentary to athlete on consecutive tests. This finding for normal subjects is in startling contrast with Bruce *et al.*'s (1953) determination of a coefficient of correlation of 0·976 on test-retest of mitral stenosis patients.

The mean oxygen consumption per square metre of body surface area of the six subjects in Group 4 during the six weeks of testing was 523 ml/M²BSA/min. The standard deviation for each individual ranges from 53·5 to 82·3 ml/M²BSA/min, indicating a normal variation of at least 200 ml/M²BSA/min, as determined by two standard deviations from the mean. Analysis of variance revealed that these differences could not be attributed to time of day and diet ($F = 1{\cdot}2$), or day of week ($F = 0{\cdot}2$). During the second and third weeks some of the subjects suffered from a mild respiratory infection which assumed epidemic proportions in the area. This condition did not affect the Bruce PFI scores, but markedly reduced the oxygen consumption, producing a difference significant at the 1 per cent level ($F = 9{\cdot}8$). When the data for these two weeks were removed from the analysis of variance, the effects of the week of training were not statistically significant ($F = 1{\cdot}3$). In

this respect total oxygen consumption would appear to be a more sensitive measure of changes in cardio-respiratory fitness than is the Bruce PFI. On the other hand it does not correlate as highly with performance in cross-country running ($r = -0{\cdot}36$) as does the Bruce PFI.

Certain theoretical objections to the design of this test appear obvious. One of its weaknesses for use with normal healthy male subjects and athletes appears to lie in the fact that the exercise is not sufficiently severe to make it possible to estimate the maximal steady state level (Wahlund 1948). A second difficulty may be that it ignores the fact that Cogswell *et al.* (1946) insist that the resting pulse rate must be included in any fitness determination using early post-exercise pulse recovery rates as factors in order to avoid erroneous impressions of comparisons between individuals having relatively high and low resting pulse rates. Basic to the whole problem, of course, is Taylor's (1944) dictum that respiratory measurements during rest and recovery, and recovery of heart rate during the first three minutes after a submaximal walk are alike unpromising as a reliable means of determining physical fitness.

§ 4. Conclusions

The results of this study support the following conclusions :

1. The Bruce PFI does not correlate well with time in cross-country running; as a predictor of performance it is not as good as the three minute post-exercise heart count.

2. Individual variations of normal subjects extend over a range of ten points ; thus a man may vary from ' sedentary ' to ' athlete ' on test-retest.

3. So far as the Bruce PFI scores are concerned, football players and cross-country runners are from different populations and cannot be described by a single point on a continuum.

4. The Bruce PFI is less sensitive to changes in cardio-respiratory fitness than is oxygen consumption.

5. The weakness of the Bruce PFI for use with normal healthy male subjects and athletes appears to lie in the fact that it does not take into consideration certain theoretical requirements for the construction of such tests.

Cet article rapporte une évaluation expérimentale de la fidélité et de la validité de l'Indice d'Aptitude Physique proposé par Bruce en vue de l'estimation de l'aptitude physique d'athlètes et de sujets sains normaux mais non-athlètes. L'Indice ne présente pas de bonne corrélation avec les performances de ' cross-country '; il est moins sensible aux modifications des aptitude cardio-respiratoires que ne l'est la seule consommation d'oxygène. D'importantes variations intra-individuelles sont mises en évidence par l'examen répété de mêmes sujets. Des sportifs de diverses catégories présentent, entre eux, des différences telles qu'on ne peut les grouper dans un groupe commun d'athlètes. Les raisons possibles de ce manque de sélectivité de l'Indice sont discutées.

Die Zuverlässigkeit und Gültigkeit des BRUCE-Index für körperliche Leistungsfähigkeit als Mass der körperlichen Leistungsfähigkeit von Sportlern und normalen gesunden Nicht-Sportlern wurden experimentell geprüft. Der Index steht in keiner guten Korrelation zur Leistung bei einem Geländelauf und ist weniger empfindlich für Aenderungen der cardio-respiratorischen Leistungsfähigkeit als der Sauerstoffverbrauch allein. Wiederholte Teste der gleichen normalen Personen zeigen grosse Variationen. Teilnehmer an verschiedenen Sportarten zerigen so gross Unterschiede, dass man sie nicht als " Sportler " in einer gemeinsamen Gruppe zusammenfasse kann. Die Gründe für diese ungenügende " Trennschärfe " des Index werden besprochen.

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THE EOSINOPENIA OF PHYSICAL EXERCISE

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1. The effect of physical exercise, largely in the form of marching with various loads, has been studied in young men.

2. All gradations were observed in the eosinopenic effect of physical exercise, varying from no detectable effect compared with control values to the virtual disappearance of the cells from the blood. The depth of the eosinopenia was proportional to the severity of the exercise. The term severity is not synonymous with metabolic cost and is more closely related to the effect of the exercise on the heart rate. For exercises of differing duration, the depth of the eosinopenia was found to be proportional to the duration of the exercise when the heart rate (not the rate of work) was kept constant. The virtual disappearance of eosinophils from the blood corresponds roughly with the inability of the individual to continue the exercise of his own free will.

3. After a moderate or severe eosinopenia occurring during the daytime the count returns to normal in the early hours of the following morning.

4. For many practical purposes it may be desirable to obtain a mean count for a group of individuals. This may be done simply by pooling the diluted blood samples from the individuals and making a count of the mixture.

§ 1. Introduction

The eosinopenic effect of physical exercise in man is now established (Rubino 1951, Domanski *et al.* 1951, Wake *et al.* 1953, Pugh 1959) and the eosinophil count is highly sensitive to various physical and emotional stresses (Selye 1950). Nevertheless there is scepticism among clinicians and applied physiologists about the potential practical value of the eosinophil count as an indication of any form of stress or fatigue, because of the magnitude of apparently random variations. Acland and Gould (1956) identified the chief sources of variation under sedentary conditions. The present paper extends their investigation to the effect of physical exertion and shows how the degree of eosinopenia is a function both of the severity and the duration of the exercise. It also shows how, by pooling the diluted samples of blood from a group of individuals, a mean count for the group may be obtained, thus reducing the effects of some sources of variation. For the full experimental data and statistical treatment the reader is referred to the original report (Redfearn *et al.* 1957).

§ 2. Methods

The subjects for the exercise experiments were 19 physically fit soldiers aged 18–25 who volunteered for the tests. The physical exertion consisted of marching for certain lengths of time at constant speeds on various gradients and carrying different loads.

The method of counting eosinophils was described by Acland and Gould (1956). 0·1 ml finger blood was taken for each count, diluted with 0·9 ml of a phyloxine–propylene glycol solution and mixed for at least 20 min in

a rotary mixer at about 25 rev/min. Two Fuchs–Rosenthal chambers were filled from each diluted sample. The eosinophil counts recorded in this paper are, unless otherwise stated, the arithmetic mean of the two chamber counts. By taking a long time (20 min) to count the two chambers, a relatively high accuracy was obtained. When the rotary mixer was used, it was found necessary to make a count less than 4 hr after sampling, as successive counts from the same samples began to fall off slightly after this time.

Five experiments are described below. The first was designed to establish the eosinopenic effect of marching and to investigate how much this effect varied over a period of a month or so. The second experiment shows the relationship between the duration of the physical exercise and its eosinopenic effect. In the third experiment the effects of exercises of differing severity were compared and the eosinophil count was followed over a period of 24 hr. The fourth experiment was undertaken to find out the degree of eosinopenia resulting from physical ‘exhaustion’. The practicability and accuracy of pooling diluted samples of blood in order to arrive at a mean count for a group of individuals was tested in the final experiment.

No particular attempt was made to control mental or emotional factors beyond ascertaining that no unusual emotional events had taken place in the lives of the subjects over the experimental periods. All experiments were conducted in a matter-of-fact and routine way and it should be noted that no unaccustomed activities were involved.

An important factor to control was the diet of the subjects on marching and resting control days. We have found empirically that the omission of breakfast and lunch usually depresses the afternoon eosinophil count by about 50 per cent compared with non-fasting days. In all the experiments reported here the same feeding arrangements held on marching and on control resting days. For the laboratory marches a variable speed, variable gradient treadmill was used. All the experiments took place in a well-ventilated room at a temperature of 20°C.

2.1. *Expt.* 1. *The Eosinopenic Effect of a Day's March*

Six subjects were used. Eosinophil counts were taken before and after marching on sixteen days during a period of one month, and at the same times on resting control days. A count was made at 8.30 a.m. ; the march commenced at 9 a.m. and was completed by 1.30 or 2 p.m. The marches consisted of 50 min of rapid marching (about 6 km/hr) followed by 10 min rest during each hour and in the main experimental period were over distances of about 25 km. They were mainly on roads in the rolling hilly countryside of Salisbury Plain. The after-march count was taken at 3 p.m., this time having been determined from pilot studies.

During the first week of the month there were no marches, the subjects being sedentary throughout the day and evening. The severe marches were on three days on each of the second and third weeks, and there were some less severe exertions during the last week of the experiment. The marching took place during May and June. Records were kept of weather conditions, which were comfortable throughout and which had no demonstrable effect on the results.

2.2. *Expt.* 2. *The Effect of Varying the Duration of the Exercise*

We have found that, so far as subjective effects are concerned, the subjective fatigue due to physical exercise is very roughly proportional to the effect of the exercise on the pulse rate. In order to submit all subjects to a standard amount of exercise from the eosinopenic point of view, it has been found convenient to exercise them at a given pulse rate rather than submitting them all to the same physical task. A rate of working which may cause one subject to give up within a few minutes because of breathlessness may be kept up for hours by another ; on the other hand, the eosinopenia, the tachycardia and the effect on the individual's power to keep going seem to run parallel with each other in different individuals to a much larger extent.

Accordingly, in the second experiment it was arranged that the subjects walked at such a speed that their pulse rates remained steady at 160/min. The rate of 160/min had been selected from pilot experiments as that rate which most fit young men could keep up for about two hours, but which afterwards left them tired and disinclined for much further effort. Six young men walked on the treadmill, which was inclined so as to give an uphill gradient of 7°. The speed of walking for each subject was adjusted every two minutes according to his pulse rate. After practice it was found possible to keep the pulse rate within about 5 beats/min of the desired figure. Records were kept of the necessary adjustments in treadmill speed, and the mean speeds for the six subjects throughout the various sessions are shown in Fig. 3. Each subject had two resting control days during which he was for most of the time sitting and for the rest walking only as necessary. There were four exercise days on which exercises of $\frac{1}{2}$ hr, 1 hr, $1\frac{1}{2}$ hr and 2 hr duration respectively were performed. The serial order of the resting and exercise days was planned as a Latin square. The exercise, if any, commenced at 10.30 a.m. Eosinophil counts were taken just before this time and at $1\frac{1}{2}$ hr intervals until 4.30 p.m. The sessions were spaced at intervals of at least a week.

2.3. *Expt.* 3. *Temporal Characteristics of the Eosinopenia*

Four subjects were marched on the treadmill, which was kept horizontal. The following marching procedures were arranged on a Latin square basis, such that each subject performed each procedure, but the order in which the subject performed the procedures was different in each case.

1. A completely sedentary day.
2. A 12 km march in denim overalls, carrying a load of approximately 30 kg.
3. A 24 km march with no load.
4. A 24 km march with the 30 kg load.

The loads were carried by means of standard (1937 pattern) Army webbing equipment. Marching commenced after the blood sampling at 10.30 a.m. and proceeded at the rate of 5·75 km/hr for 50 min in each hour, followed by 10 min rest. A break of half an hour was made for lunch on the longer marches. Counts were taken every two hours throughout the 24 hours after the first blood sample. After the march was completed the subject indulged in no appreciable exertion. Apart from being awakened for blood sampling, subjects slept normally, from about 10.30 p.m. to about 8 a.m. the next day.

2.4. *Expt.* 4. *Marching to 'Exhaustion'*

Three volunteers were asked to march uphill (2·5° slope) on the treadmill, unladen, at 6·4 km/hr, for 45 min in every hour, the remainder of the hour being spent sitting during the performance of psychological tests. The subjects were asked to keep up this arduous routine for as long as they felt able, and they only discontinued when they felt more or less 'fit to drop' and unable to keep up with the speed of the treadmill. Sandwich lunches were taken at the same times on exercise and on resting control days. Eosinophil counts were taken before the exercise and at two-hourly intervals subsequently.

2.5. *Expt.* 5. *Obtaining a Mean Count for a Group of Individuals*

Diluted samples of blood from additional groups of similar subjects were pooled by mixing aliquot portions of the individual diluted samples. The samples of blood from the different individuals were diluted to 1 in 10 with the phyloxine–propylene glycol solution, the diluted samples were then mixed and the mixture counted in the normal way without serious interference from agglutination or other mixing effects. A mean count for the group of individuals was thus obtained, the count from each chamber then being subject to the same error as is shown by the individual chamber counts before mixing.

§ 3. Results

3.1. *Expt.* 1. *The Effect of a Day's March*

In Fig. 1, where the geometric means of the counts are shown, the marching days have been marked with arrows, and it is immediately apparent that on these days the afternoon count is greatly and consistently depressed compared

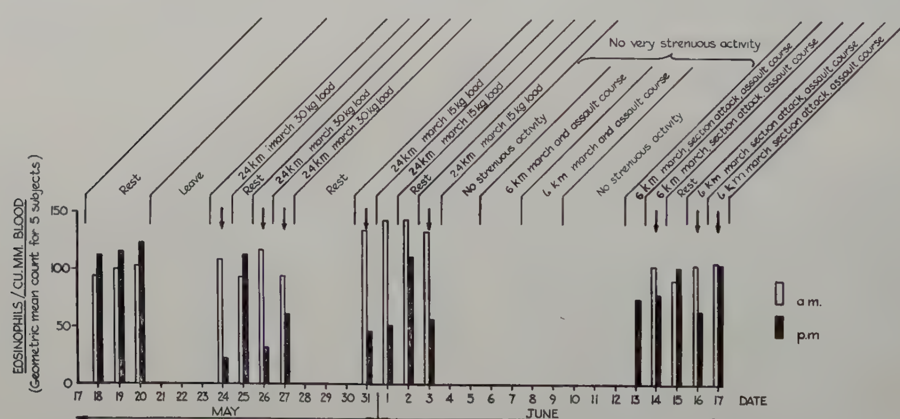

Figure 1. Mean morning and afternoon counts for the five subjects on marching days (arrowed) and on resting control days.

with that on resting days. Whereas on resting days the afternoon count is usually about 120 per cent of the morning count, after a 24 or 25 km march the afternoon count is only from 20 per cent to 50 per cent of the morning count. The effect of the two-hour exercise consisting of a march of 6 km, a mock attack on a position and a round of an obstacle course was much smaller than the effect of the longer march.

The marches performed on 24, 26 and 27 May were exactly the same as each other, being over the same road and in similar weather. The first of the three marches was found particularly tiring by the men, occurring as it did after a fortnight of inactivity. The second and third were progressively less fatiguing, as judged by the men's statements. It is notable that the eosinopenia due to the first march is particularly profound, while those due to the second and third marches are progressively smaller. Similarly, the marches on 31 May, 1 June and 3 June, while differing slightly from those of the previous week, were identical with one another, and showed a sequential effect, smaller than but otherwise comparable with that of the first week's marches. No such sequential effect could be demonstrated during the final week of the experiment, when the exercise was much less severe, and the subjects by now in good training.

On 24 May one subject had to discontinue his march after 15 km because of fatigue culminating in abdominal pain and vomiting. These abdominal symptoms are, of course, quite common in acute physical fatigue, but in his case were no doubt partly due to a very mild digestive disorder during the previous night which he had not thought worth reporting. His afternoon count on 24 May was only three cells per mm^3.

When the results from 18 May to 3 June were examined, it was noticed that there had been a tendency for the morning counts to rise progressively during this period (Fig. 1). In order to determine the approximate duration of this effect, more counts were made after a further two weeks of the trial had elapsed. Meanwhile the men had continued with a moderate amount of activity but their exertions had not been by any means as severe as during the first two weeks. By now the level of the morning counts had returned to normal.

3.2. *Expt. 2. Varying Durations of Exercise*

The geometric mean counts of all the subjects for the different durations of exercise at the various times of day are presented in Fig. 2. For plotting the data in this way, each count was first expressed as a ratio of the subject's 10.30 a.m. count on that particular day, and the geometric means of the ratios for the six subjects then calculated. Expressing each count as a ratio of the pre-exercise count eliminates the effect of day-to-day fluctuations in level and of individual variations in general level. Ratios and geometric means were used because variation in the eosinophil count occurs on a proportionate rather than absolute basis, as shown by Acland and Gould (1956) and confirmed by the present data.

Figure 2 demonstrates that as the duration of the exercise is prolonged, the resulting eosinopenia becomes progressively more profound. The impression is gained that, compared with the corresponding resting counts, the counts at 3 p.m. and 4.30 p.m., when the eosinopenia is maximal, show a diminution which is roughly proportional to the duration of the exercise. This impression receives support from examination of the lower part of Fig. 3, which shows the mean eosinopenia as a function of duration of exercise. The eosinopenia is expressed as the percentage reduction of eosinophils compared with the mean values for the resting days for corresponding times. It is well known that the eosinopenic effect of an acute

Table 1. The effect of different durations of exercise on the eosinophil counts of six normal subjects

Subject	Exercise	Eosinophils per cm³					Order in which performed
		10.30 a.m.	12 noon	1.30 p.m.	3 p.m.	4.30 p.m.	
A	Resting (1)	106	95	84	97	123	1st
	½ hr	65	45	40	54	61	3rd
	1 hr	75	28	15	23	34	4th
	1½ hr	76	65	28	28	53	2nd
	2 hr	75	61	14	9	14	6th
	Resting (2)	78	50	98	98	104	5th
B	Resting (1)	382	354	310	326	367	2nd
	½ hr	337	307	360	353	460	1st
	1 hr	446	446	200	222	332	5th
	1½ hr	175	257	69	54	93	3rd
	2 hr	257	280	95	53	97	4th
	Resting (2)	348	353	343	384	417	6th
C	Resting (1)	83	123	150	93	123	3rd
	½ hr	101	83	83	104	115	5th
	1 hr	103	108	58	48	67	6th
	1½ hr	108	58	31	29	40	1st
	2 hr	81	84	34	14	29	2nd
	Resting (2)	81	126	100	101	140	4th
D	Resting (1)	137	159	198	270	214	4th
	½ hr	162	129	161	106	193	2nd
	1 hr	231	209	218	229	259	3rd
	1½ hr	176	259	146	117	126	6th
	2 hr	159	212	76	175	159	5th
	Resting (2)	202	225	218	254	250	1st
E	Resting (1)	279	310	387	292	375	5th
	½ hr	376	298	284	332	312	6th
	1 hr	288	292	274	364	445	2nd
	1½ hr	326	395	231	225	193	4th
	2 hr	389	384	170	109	129	1st
	Resting (2)	250	257	309	301	309	3rd
F	Resting (1)	190	228	175	234	243	6th
	½ hr	95	87	133	137	165	4th
	1 hr	109	83	126	139	130	1st
	1½ hr	214	154	162	183	184	5th
	2 hr	111	104	89	61	70	3rd
	Resting (2)	222	218	298	331	274	2nd

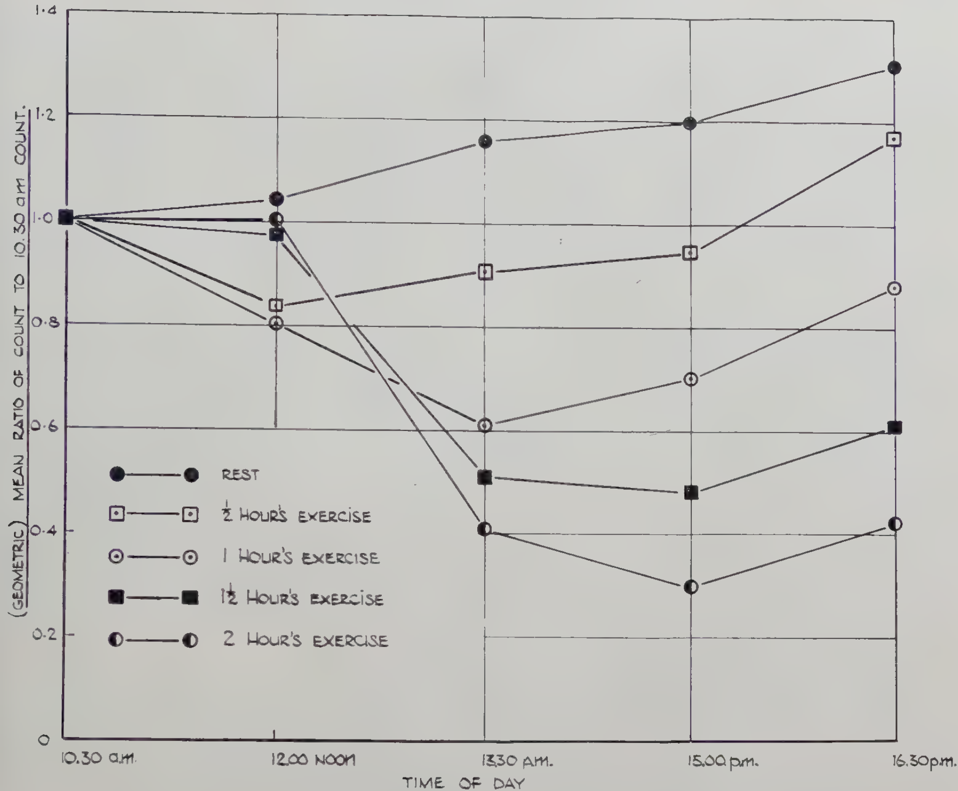

Figure 2. Eosinopenic effects of exercises of differing duration.
Each curve represents mean values for the six subjects.

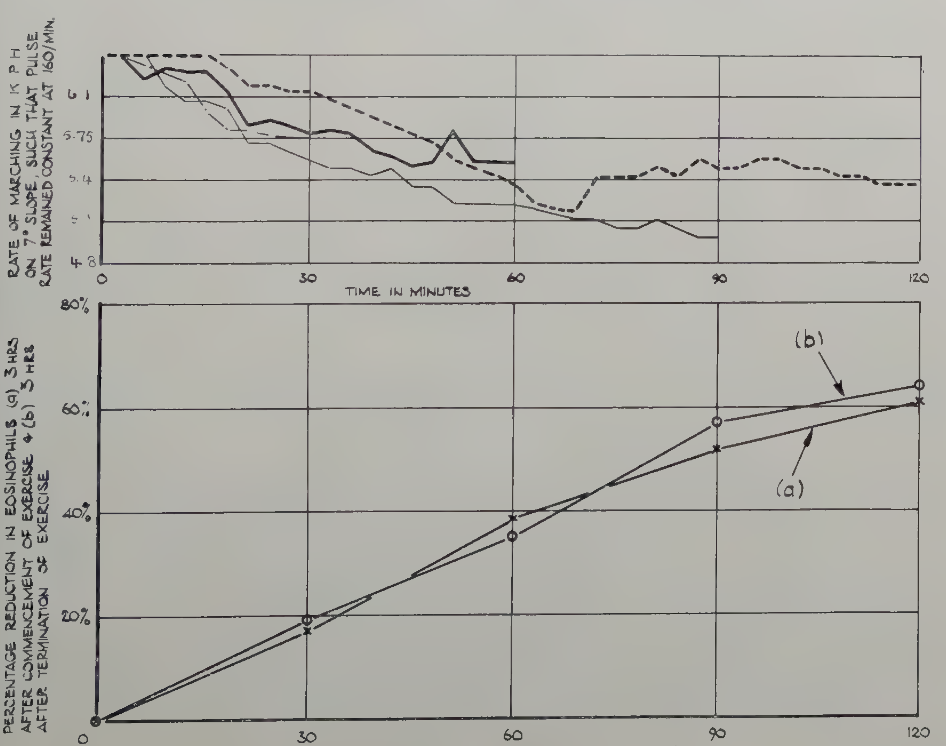

Figure 3. The top graph shows the decline in the marching speed (mean for six subjects) as the exercises of differing duration progressed. The bottom graph shows the eosinopenic effects of the exercises as a function of duration.

stress is maximal about three or four hours after the stress. There would be objections against comparing values at a fixed time after the commencement of stresses of different duration, just as there would be objections against comparing values at a fixed time after the termination of such stresses. The curves for the eosinopenia three hours after the commencement and three hours after cessation of the exercise are therefore both presented.

The proportionate relationship between duration of exercise and eosinopenia does not hold for the longest duration of exercise, when the increment in eosinopenia falls off slightly. It is possible that under the conditions of this particular experiment, owing to the progressive reduction in treadmill speed, the subjects were able at about this time to arrive at some sort of balance between work load and stress, such that the work load could have been kept up for several hours longer. This state of affairs is suggested in the upper part of Fig. 3, where the mean treadmill speed is shown as a function of time for the exercises of differing duration. It can be seen that whereas for the first 70 min or so the treadmill speed has to be progressively reduced, after this time no further reduction is necessary. For the particular subjects used, this steady rate of walking, i.e. 3·4 miles per hour up a gradient of 7°, would correspond to an energy expenditure of very roughly 9 kcal/min in excess of the basal metabolism (Redfearn *et al.* 1956).

It follows from Fig. 3 that if the exercise had been kept above this level of nine working kcal/min, the relationship between duration of exercise and eosinopenia would not have been linear. If the treadmill speed had been kept constant instead of being progressively reduced, it seems certain that the eosinopenic effect of each succeeding half-hour would have been greater. In practice, however, exhaustion would rapidly have supervened, which is one of the chief reasons why the experiment was planned in terms of a constant pulse rate rather than a constant exercise.

An analysis of variance was carried out on the data (see Redfearn *et al.* 1957). This showed that the duration of exercise has a statistically highly significant effect on eosinophil density.

3.3. *Expt.* 3. *Temporal Characteristics of the Eosinopenia*

The relative magnitudes and durations of the eosinopenia due to the different exercises are shown in Fig. 4, where the same method of plotting has been used as in Fig. 2.

It can be seen that the depressant effect of the marches on the eosinophil count is proportionately greatest at about 6.30 p.m., that is, some $2\frac{1}{2}$ hours after the 24 km march had been completed. We have found that exercises lasting only a few minutes also have their maximum effect some three hours after the exercise. The effect of exercises lasting longer than five or six hours may be maximal less than two hours after the end of the exercise. Following the day's march, the count returns to normal in the early hours of the next morning. This has been confirmed in many other experiments.

It is clear from Fig. 4 that the heavier exercise results in the greater eosinopenia. The addition of a 30 kg load to an average unladen subject walking at 5·75 km/hr on the level would increase his working metabolism (i.e. his energy expenditure over and above his resting metabolism) by about

50 per cent (Redfearn *et al.* 1956). Thus, if the 24 km march without a load caused an expenditure of 50 units of energy, the same march when laden would expend 75 units, and a march of half this distance laden would use 37·5 units. The respective percentage depressions in the eosinophil count at 6.30 p.m. are approximately 50, 75 and 40, suggesting an approximately linear relationship between the energy cost of a piece of moderate work and its eosinopenic effect, irrespective of duration.

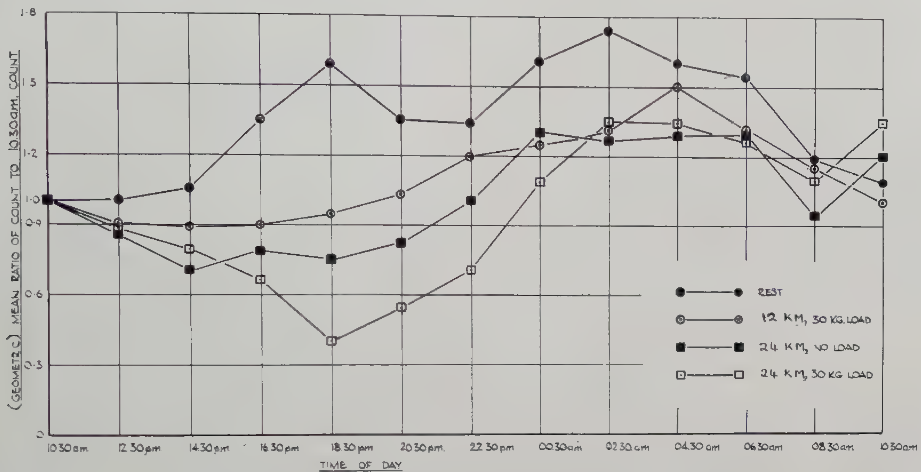

Figure 4. Eosinopenic effect of different exercises.
Each curve represents the mean for four subjects.

Analysis of variance gave results analogous with those of the last experiment, and in particular it was noted that the 'between-exercises' effect was very highly significant.

3.4. *Expt.* 4. *Marching to 'Exhaustion'*

The results for one of the subjects, typical of all three, are presented in Fig. 5. It is clear that exercise of this severity causes an eosinopenia of 90 per cent or thereabouts, returning to control values during the early hours of the following morning.

A fourth individual (Expt. 1) had to discontinue a route march on 24 May 1955 on account of 'exhaustion'. His count after the march in question was down to about 3 per cent of his corresponding control values.

It would be difficult to obtain more severe fatigue than that shown by these subjects under experimental conditions. However, if life depended upon it, or under the strength of motivation obtaining frequently in competitive sport, there is little doubt that more severe fatigue could occur.

None of the subjects mentioned in these experiments had any special incentive for the exercise except desire to help in the investigation, but a very distinct effort of will was required to continue for so long. Thus it was not possible to assert that the eosinopenia was entirely due to physical exercise and not to mental or emotional factors. It can, however, be claimed that the only emotional factor involved in these experiments was the conflict between the desire to give up and the intention to carry on for as long as physically possible.

3.5. *Obtaining a Mean Count for a Group of Individuals*

In five experiments, each on groups of 8 to 20 subjects, the counts from the pooled samples (six chambers averaged) differed from the arithmetic mean count of the individuals by 0·28, 1·19, 0·55, 1·18 and 1·06 per cent respectively.

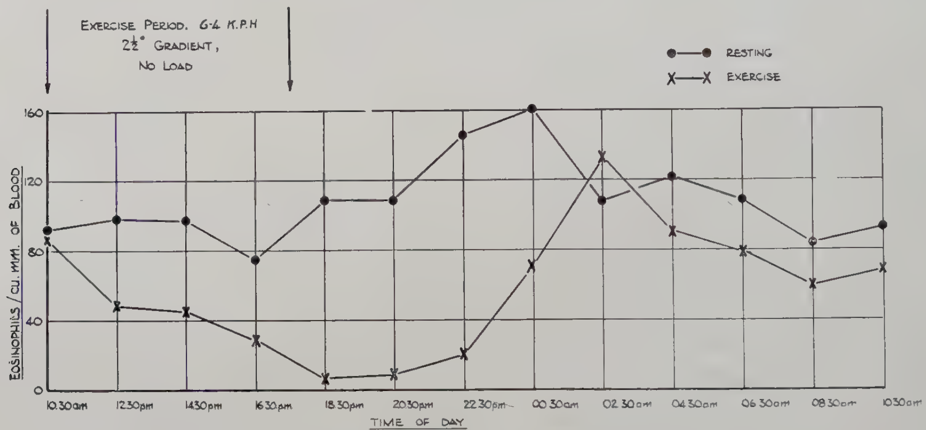

Figure 5. Eosinopenic effect of an exercise to ' exhaustion ' compared with a resting day in one individual.

Thus it is clear that an accuracy within 1 per cent or 2 per cent of the ' true mean ' count for the group can reasonably be expected if several chambers of a mixed diluted sample are counted and averaged. In these experiments the aliquots were all taken with the same pipette, which was not washed or dried between aliquots, so there is no doubt that still greater accuracy could be achieved.

§ 4. *The Detection of Differences in Eosinopenic Effect*

For practical purposes it may be desirable to distinguish between the eosinopenic effects of alternative ways of performing a physical exercise. A satisfactory way of eliminating unwanted sources of variation has been described (Redfearn *et al.* 1957). Using this method, two load-carrying equipments were compared in their effect on soldiers on a day's march, with results shown in Table 2.

Table 2. Ratios of the pre-march to post-march counts. Each count was the mean of eight chambers obtained by mixing the diluted samples from approximately 26 subjects*

	Group A	Group B	Mean ratio
Equipment 1	1·5	1·75	1·67
Equipment 2	1·25	1·37	1·31

* Unfortunately five subjects were not present on one day.

Questionnaires showed that the much less eosinopenic equipment 2 was preferred by three men to one. Subsequent field trials of a similar nature have further validated the eosinophil count. Energy expenditure measurements failed to distinguish between the two equipments.

§ 5. Discussion

These results show that the eosinophil count is depressed progressively both with increasing severity and increasing duration of physical exercise, and that in states of exhaustion the count is depressed almost to zero. The data from Expt. 1 suggest that if a severe exercise is repeated, the eosinopenic effect falls off progressively as the subject becomes fitter and as the subjective effect of each succeeding exercise falls off. Similar findings are reported by Pugh (1959).

Individual differences in general level, diurnal patterns which vary somewhat from one individual to another, and individual differences in response to exercise all contribute to the variation in the eosinophil count as well as the effect of physical exercise. It is therefore essential when investigating the effect of exercise to use individuals as their own controls, to take counts at the same time of day on control and experimental days, and to keep emotional and dietary factors as constant as possible. When this is done the eosinophil count is probably the most practical way of assessing the ' stress ' of a physical exercise, although it is not correct to interpret this stress as in any way harmful. Subjectively it seems to correlate highly with the feeling of tiredness, and this state is, of course, not necessarily harmful or unpleasant.

The reason for the eosinopenia is still in doubt. For several years after Selye's description of the general adaptation syndrome, it was thought that the eosinophil count was a reflection of the state of activation of the adrenal cortex by the hypophysis, and that adrenaline produces eosinopenia by acting on this latter organ (see, for example, Recant *et al.* 1950). It was later shown, however, that the effect of adrenaline on the eosinophil count in adrenalectomized subjects is comparable with that in normal subjects (Thorn *et al.* 1953). Thus the presence of the hypothalamus–pituitary–adrenal system is not necessary for the greater part of the effect, but there is evidence (see Gordon 1955) that the presence of adrenal cortical hormones or functioning adrenal remnants is essential for adrenaline eosinopenia.

The amount of adrenaline liberated into the circulation as a result of physical exertion is not yet precisely known. However, the size of the increase in urinary adrenaline excretion following physical exertion is approximately known (Euler and Hellner 1952), and also the urinary recovery of intravenously infused adrenaline (Euler *et al.* 1954). Multiplied together the values given by these authors suggest that a moderate day's march might be expected to cause secretion of about 0·1 mg of adrenaline, which would produce an eosinopenia in the region of 50 per cent (Recant *et al.* 1950). Pending more accurate information it may therefore be assumed that the secretion of adrenaline due to physical exertion might account completely for the eosinopenia.

The diurnal pattern of the count might be a result of fluctuations in the level of the circulating adrenaline, if the latter, as would be expected, varies in parallel fashion with other related phenomena such as diurnal variations in temperature, blood pressure, and various psychomotor functions. Besides changes in adrenaline level, variations in activity of the reticulo-endothelial system, and fluctuation in 5-hydroxytryptamine levels (Visscher and Halberg 1955) would be expected to vary the rate of eosinophil destruction, in addition to the effect of cortical hormones.

There also seems to be a feedback mechanism controlling the count, at least in adrenalectomized mice (Durgin and Meyer 1951). The eosinopenia caused by the injection of adrenal cortical extract in these animals is followed some hours later by an increase in the number of young forms in the bone marrow, which causes the blood eosinophil count greatly to overshoot its control level some twelve hours after the injection. In the present experiments no marked overshooting occurs, but this does not exclude a similar mechanism.

It is a pleasure to acknowledge my great debt to Mr. T. L. Dickens of A.O.R.G. for organizing all administrative details and making the eosinophil counts.

1. L'effet de l'exercice musculaire a été étudié chez des hommes jeunes, effectuant de la marche avec différentes charges et sur différentes pentes.

2. L'effet de l'exercice physique sur la teneur du sang en éosinophiles présente toutes les gradations possibles, depuis l'absence d'effet par rapport aux valeurs de contrôle, jusqu'à l'absence virtuelle de ces cellules dans le sang. Le degré d'éosinopénie est apparu proportionnel à la sévérité de l'exercice. Le terme de sévérité n'est pas synonyme de dépense énergétique mais est plus étroitement en rapport avec l'effect de l'exercice sur la fréquence cardiaque. Pour des exercices de durées différentes, le degré d'éosinopénie a été proportionnel à la durée de l'exercice quand la fréquence cardiaque (et non la puissance musculaire développée) était maintenue constante. La disparition virtuelle des éosinophiles du sang se produit approximativement lorsque l'individu devient incapable de poursuivre le travail de son plein gré.

3. Aprés une éosinopénie, modérée ou importante, apparue pendant la journée, le taux d'éosinophiles revient à la normale aux premières heures du jour suivant.

4. Pour de nombreuses raisons pratiques, il peut être utile d'obtenir un taux d'éosinophiles moyen pour un groupe d'individus. Ceci peut être fait simplement en mélangeant les échantillons dilués des sangs individuels et en procédant à une numération sur le mélange.

1. Die Wirkung körperlicher Arbeit, hauptsächlich in Form des Marschierens mit verschiedenen Lasten, wurde an jungen Männern studiert.

2. Alle Grade der Wirkung von körperlicher Arbeit auf die Abnahme der eosinophilen weissen Blutzellen ("Eosinopenie") von eben erkennbarer Verminderung im Vergleich zu Kontrollwerten bis zum völligen Verschwinden kamen vor. Die Stärke der Eosinopenie war der Schwere der Arbeit proportional. Der Ausdruck "Schwere der Arbeit" ist nicht gleichbedeutend mit der Stoffwechselzunahme, sondern steht in engerer Beziehung zu der Wirkung der Arbeit auf die Herzfrequenz. Bei Arbeiten verschiedener Dauer war die Stärke der Eosinopenie der Dauer der Arbeit proportional, wenn die Herzfrequenz (nicht die Arbeitsschwere) konstant blieb. Das völlige Verschwinden der Eosinophilen entsprach praktisch der Unfähigkeit einer Person, die Arbeit aus eigenem Antrieb fortzusetzen.

3. Nach mässiger oder schwerer Eosinopenie während des Tages kehrt die Zahl der Eosinophile in den frühen Stunden des folgenden Tages zur Norm zurück.

4. Für viele praktische Zwecke könnte es wünschenswert sein, einen Mittelwert für eine Gruppe von Personen zu erhalten. Das könnte einfach durch Mischung der verdünnten Blutproben und durch Zählung der Eosinophile in der Mischung erfolgen.

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HUMAN POWER OUTPUT: THE MECHANICS OF POLE VAULTING

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Slow motion cine-photography has been used to study the performance of pole vaulters. By plotting the trajectory of the centre of gravity, it can be shown that most of the energy required is stored in kinetic form during the run-up; unfortunately, a high initial speed (high initial kinetic energy) seems to be attended by correspondingly large losses during the rest of the vault. The most successful performers take off at moderate speed and add to their energy by active performance of work while they are swinging up on the pole.

§ 1. Introduction

When an athlete competes in throwing the javelin, putting the shot or tossing the caber, he attempts to impart as much kinetic energy as possible to a projectile and to despatch it in a certain critical direction. The laws of ballistics can be applied with relative simplicity and the work output can be calculated. However, when an athlete attempts the long jump, high jump or pole vault, his own body is the projectile, and the problem of analysing the complicated series of airborne movements which he performs is added to all the other technical problems of recording and evaluation. The pole vault is even more difficult to analyse (*a*) because of the complexity of movement and (*b*) because of the use of an auxiliary object—the pole.

To study such an athletic performance one must begin with slow motion cine photographs in order to record what movements are taking place. There was an opportunity to study pole vaulters in this way during practice for the VIth Empire and Commonwealth Games in the summer of 1958. The records so obtained have been analysed in an attempt to account for the changes in energy that occur before and during the vault.

§ 2. Experimental Technique

Records were obtained of five men pole vaulters, including the ultimate winner of the event, doing ten practice vaults over heights up to 13 ft. The competition was subsequently won with a vault of 13 ft 8 in.

Camera: A Kodak Cine Special camera was used, with a 2·5 cm (1 in.) lens. The shutter was set to 64 frames per second, which achieved a slowing down of motion and an unblurred image of the athlete, the effective exposure being 1/120th sec. The camera was set up about 100 ft from the vaulting path and at right angles to it. Seen through the viewfinder, the athlete appeared running across the frame and vaulted after about 10 paces, after which he picked himself up and left the picture (see Fig. 1).

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Calibration: The following calibrations were made:

(*a*) From the uprights, at exactly 2 ft intervals, bright metal stakes were inserted along the run-up and vaulting path. They were continued for a few feet in front of the sand pit.

(*b*) The uprights holding the bar were carefully marked in feet. In practice it is easier to attach a strip of metal that has been painted black and white alternately at foot intervals. This shows up easily on the film. The pole itself may be similarly marked if a study is to be made on grip-distances; the present work did not necessitate this.

(*c*) A check was made on the shutter speed by including within the range of the camera a light connected to a chronometer, or to an electric timer, to give flashes at $\frac{1}{2}$ sec intervals. It is essential to use a lamp with a short decay-time, otherwise there is no clear-cut ON–OFF and it is difficult to decide exactly at which frame the light comes on. Incandescent bulbs have a long after-glow; gas discharge types (neon, xenon) are more suitable. If the time flasher is not actually built into the camera, its light output should be strong enough to be seen in bright sunshine. The average time interval on the film between frames was estimated for each film sequence by use of the flashing light clock.

Examination of film: After the pole vault had been photographed, the films were processed, titled and made into a series of short loops. Careful notes were made about each vault.

The data were extracted by tracing the projected image in the following way. The film was inserted in a 'Specto' single-frame analysing projector and focused onto a large sheet of white card (30 in. × 24 in.). First of all, the landmarks were pencilled in, viz. the uprights and the line representing the path of the run-up with 2 ft intervals showing as points of bright metal along this line. In the films taken the gable of a house in the background was noted, and this triangle provided a speedy and accurate way of aligning the film.

During its movements through the camera and the projector, small changes in alignment of the framed film occur; as each frame is viewed, it is necessary to reposition the projector so that the reference points remain fixed. A suitable method is to have the projector standing on a sheet of sponge rubber; gentle pressure at one or two points on the body of the machine achieves side-to-side or up-and-down alignment. The new position is held until the data for that frame have been obtained.

Movements of the centre of gravity of the body: In plotting these movements, the problem arises of locating the centre of gravity in relation to the projected image of the vaulter. In a standing man, the centre of gravity lies on the line joining the anterior superior iliac crests; when the body is flexed the centre of gravity moves forwards and slightly upwards. Preliminary experiments with a manikin enabled us to form some estimate of the position of the centre of gravity in relation to the rest of the body in the various postures encountered in pole vaulting. As each frame was projected, the most likely position of the centre of gravity was marked on the sheet of cardboard. Care was taken to mask from view the points derived from previous frames. This obviated any tendency to give a spurious smoothing to the trajectory. When the action

on the film was completed, the trajectory was indeed found to be a smooth line, thus confirming that the assessment of each centre of gravity position was reasonable. The more elegant methods for obtaining the centre of gravity (Fenn 1930, McIntosh 1958) require much longer time; they do give a precise answer which is not necessary however for this study. In practice every frame on the film was used; since the action lasted about 5 sec, 150–200 dots were plotted to trace the path of the centre of gravity.

§ 3. Results

A typical result is shown in Fig. 1. On analysis of the ten vaults it was found that they all conformed to a standard pattern:

(1) Run up, accelerating to maximum speed several feet before planting the pole.

(2) Deceleration while planting the pole and slight acceleration while leaving the ground.

(3) Change in direction and velocity about 0·4 sec after take-off.

(4) Change in posture to clear the bar and to discard the pole shortly before reaching the peak of flight.

(5) Free fall under gravity to landing pit.

Velocities were measured at various key points during each vault. The athletes approached the vault at velocities from 21 to 31 ft per sec and were moving horizontally at 5 to 10 ft per sec at the top of their flight.

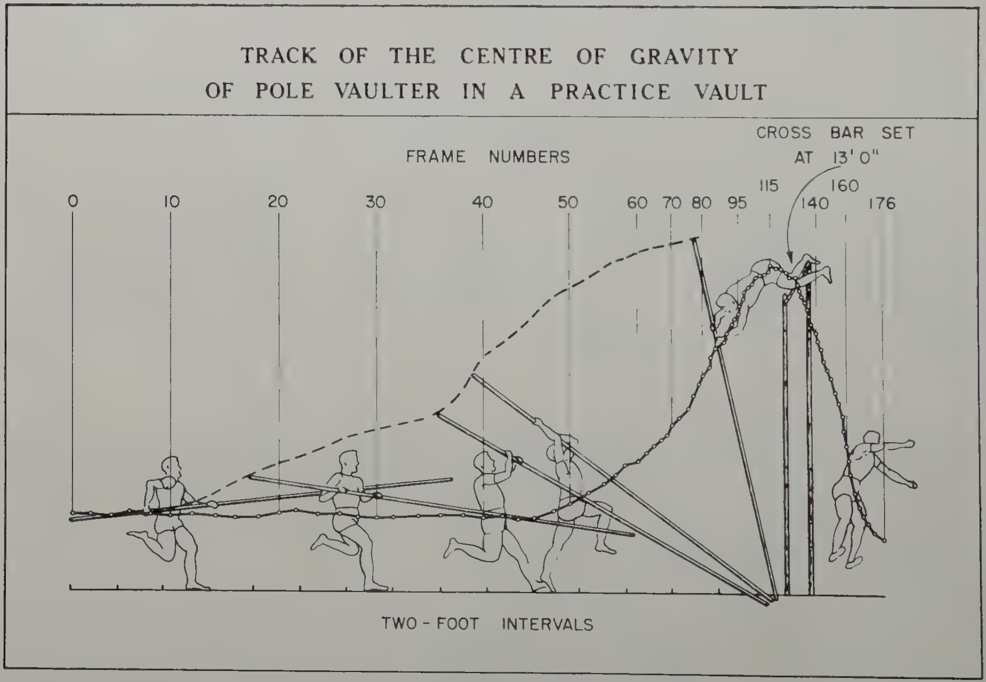

Figure 1. Tracks of the centre of gravity and of the top of the pole during a practice vault. The frame numbers refer to the position of the centre of gravity which is marked with a circle every 1/16 sec (i.e. every 4th frame of film taken at 64 frames per sec.).

From a mechanical point of view, the vaulter stores kinetic energy in his body during the run-up. After leaving the ground he makes use of the pole to alter his direction of motion so as to convert this kinetic energy into potential energy.

To a first approximation, the height risen corresponds to the initial kinetic energy, as shown by the crosses in Fig. 2.

The kinetic energy has been calculated from the velocity just after take-off:

$$KE = \frac{MV^2}{2g} \text{ (ft lb)}$$

or

$$= \frac{V^2}{2g} \text{ (ft lb)/lb body weight.}$$

The second form is useful because it is possible to plot together the results from subjects of different weight, and complications due to the mass of the pole are almost eliminated. If no energy is lost or gained after leaving the ground, i.e. if it is all devoted to rising as high as possible, then height risen $= V^2/2g$ ft.

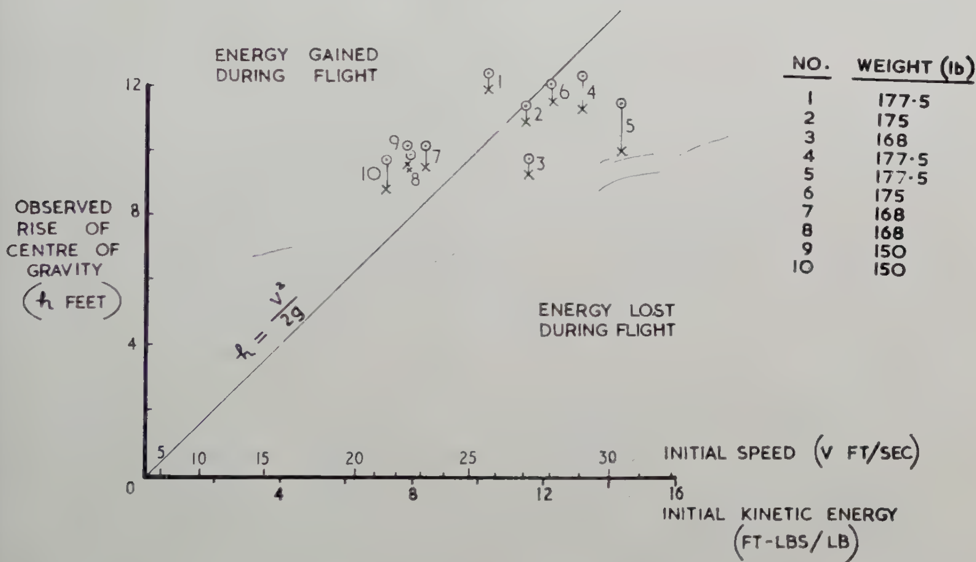

Figure 2. Observed rise of centre of gravity plotted against initial kinetic energy (crosses). Each circle shows how high the jump would have been if the final velocity of the jump was zero, that is to say all the initial kinetic energy had been converted into potential energy (see text).

This line has been drawn in Fig. 2 and it is evident that in half the vaults energy was gained, and in half it was lost during flight.

Energy can be gained in only one way, by thrusting downwards on the pole and thus performing muscular work. During the process, if the pole is bent, some energy will be stored for a time as elastic energy. On the other hand, energy can be lost in various ways—through friction with the air, or between the pole and the box; as a result of stretching active muscles ; or by retaining some kinetic energy of rotation or translation. The last two items come into a special category, since gymnastic manoeuvres that make it possible to clear the bar with a minimal rise of the centre of gravity may well be worth their energy cost, and it is essential to have some forward velocity in order to clear the bar.

The effect of the last item can be calculated from the measured horizontal velocity at the highest point of the vault. Each circle in Fig. 2 shows how high the jump would have been if the final forward velocity at peak of flight had been zero, so the line joining cross to circle represents the amount of energy corresponding to the final horizontal speed. This amount is very variable; from 0·42 (ft lb)/lb = 0·42 ft, in vault 3 to 1·43 (ft lb)/lb = 1·43 ft in vault 5. The lower velocity sufficed for clearing the bar, and the higher velocity represents a waste of energy with no compensating gain.

The other sources of energy loss cannot be so easily calculated. They were probably quite large, but were masked to a varying degree by the performance of muscular work. Even in the most favourable case, e.g. No. 1 (Fig. 2), the net power production was 0·6 h.p. averaged over the 1·16 sec occupied in flight, but the actual power produced by the muscles may have been a good deal greater.

The initial kinetic energy increases steeply as initial speed is increased, but the utilization of this energy also becomes less efficient (see vaults 4 and 5), presumably because coordination is impaired by haste. The final speed in these two vaults was unduly high and there was a net loss of energy while the vaulter was airborne. The most successful jump (No. 1), is characterized by moderate initial speed, low final speed at peak and a large performance of work during flight. Even so, more than 80 per cent of the energy had been accumulated during the run-up. An attempt was also made to correlate the height reached with various other features of the performance (using Kendall's rank correlation method (Kendall 1948)), in the hope of identifying more of the ingredients of a successful vault. There is some evidence that a shallow trajectory after take-off, and a long delay before swinging up on the pole, are both favourable ; but there is at present insufficient evidence to draw firm conclusions.

Le saut à la perche a été étudié par ciné-photographie au ralenti. En dessinant la trajectoire du centre de gravité, on constate que la plus grande partie de l'énergie requise est accumulée sous forme cinétique pendant la course d'élan ; malheureusement, une vitesse initiale élevée (importante énergie cinétique initiale) semble être liée à une perte proportionnelle d'énergie pendant la phase ultérieure du saut. Les sauteurs les plus experts prennent leur élan à vitesse modérée et fournissent un supplément d'énergie par une action musculaire énergique pendant la phase de redressement de la perche.

Die Leistung von Stab-Hoch-Springern wurde mit Zeitlupen-Kinematographie studiert. Aus dem Verlauf der Kurve des Schwerpunktes des Springers kann entnommen werden, dass der grösste Teil der benötigten Energie in kinetischer Form während des Anlaufs gespeichert wird ; unglücklicherweise scheint eine hohe Ausgangs-Geschwindigkeit (hohe Ausgangs-Kinetische Energie) von einem entsprechend grossen Verlust während des weiteren Verlaufes des Sprunges begleitet zu sein. Die erfolgreichsten Springer setzen bei mässiger Geschwindigkeit ab und vermehren ihre Energie durch aktive Arbeitsleistung, während sie sich am Stab hochschwingen.

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PROBLEMS IN HUMAN VIBRATION ENGINEERING

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Vibration is considered to include the oscillatory motion of travelling vehicles. The predominant linear sinusoidal component of this motion is usually in the vertical direction and of 0–50 c.p.s. in frequency. A human being or animal subjected to vibration may exhibit a variety of symptoms and anatomical damage. These effects may be diminished by shielding the operator from the vibration of the vehicle. Excessive shielding is undesirable in that it increases the relative motion of the operator with respect to the vehicle and hence may be expected to cause decrement of performance. Some of the physical theory necessary for the design of vibration shielding equipment is given. Methods for human vibration protection are described and reference is made to a currently available device.

§ 1. Introduction

The oscillatory motion experienced by the operators of vehicles which travel over bumpy roads or through turbulent air is commonly called vibration. The effects of this motion on the driver or pilot and the methods of prevention will be discussed in this paper.

Vibratory motions are usually studied most conveniently if the motion is considered to consist of the vector sum of three linear components at right angles to each other, plus three angular components. The effects of angular vibrations on man have not been studied, except in connection with motion sickness. It is said that, in most land and air transportation equipment, the linear component of vibration in the head-to-seat direction is of considerably greater magnitude than the other linear components and, for this reason, has been subjected to more experimental study. The vibratory motion encountered in vehicles usually has an irregular wave shape, but generally is studied most conveniently if it is considered as a sum of sinusoidal waves of some fundamental frequency and all integral multiples thereof, the amplitude of each sine wave being determined by the methods of Fourier analysis. It is said that the predominant frequencies of mechanical vibration of land, sea and air vehicles are usually below 50 c.p.s., therefore the present discussion is confined to this range. Some of the effects of higher frequencies are dealt with in works on sound.

It would seem reasonable to suppose that vibrations can affect man only to the extent that they are transmitted to the parts of his body. Hence, the first section of this paper will be devoted to the ways in which vibration is transmitted from vehicle to man, and to the methods of preventing such transmission. That portion of the vibration which reaches the man can cause a variety of anatomical, physiological, and performance changes which are discussed in the second portion of this paper. This is followed by an effort to relate the experimental work on vibration to practical problems, which leads to a description of practical methods and equipment for protection against vibration.

§ 2. Transmission of Vibration from Environment to Man

Transmission through the seat is probably the most important path by which vehicular vibration reaches the human operator. If a man sits on a hard seat on a shake-table which undergoes sinusoidal vibration in the head-to-seat direction, it is found experimentally that the vibration of the man is of the same frequency as the vibration of the seat (Müller 1939). If vibration recorders are attached firmly to the seat and to the man's head, it is possible to determine what percentage of the amplitude of vibration of the seat reaches the head for different vibration frequencies. The three available studies of this type (Müller 1939, Latham 1957, Dieckman 1958) all show the same general pattern of transmission versus frequency, although the curves differ in detail because of differences in recording methods and because of differences between the mechanical characteristics of different subjects. Typical of the results obtained are the curves for two different subjects shown in Fig. 1.

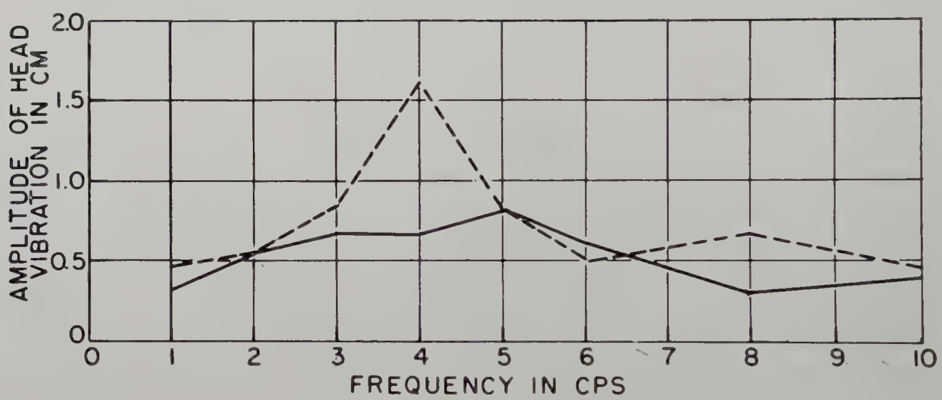

Figure 1. Amplitude of vertical vibration of head of two different subjects sitting on a shake-table (no cushion). Shake-table vibrates at an amplitude of 0·4 cm. After Müller (1939).

In general, at a frequency of 0–1 c.p.s., the head vibrates at somewhere near the amplitude of the seat but, as frequency increases, the amplitude of the head vibration increases and reaches a peak amplitude somewhere between 3–6 c.p.s. At the frequency at which maximum head vibration occurs (called the resonant frequency), the head vibrates at an amplitude equal to 150–300 per cent of the seat amplitude. As frequency increases above resonance, the amplitude of head vibration decreases and at approximately 10 c.p.s., head and seat vibrate at equal amplitudes. Seat–head transmission decreases progressively at higher frequencies, so that at 70 c.p.s., only about 10 per cent of the amplitude of seat vibration may be expected to reach the head (Coermann 1939). In addition to the main resonance point mentioned above, there are one or two secondary resonances (Latham 1957) apparently due to a shoulder–head transmission resonance at 20–25 c.p.s. (Dieckman 1958). In the present author's experience, measurements of vibration of any part of the body other than the head are always open to question because of the difficulty of preventing motion of the recording accelerometer relative to its site of attachment on the body. When a man is subjected to vertical vibration, a front-to-back component of head vibration is generated in addition to the vertical component (Dieckman 1958).

As an aid to the understanding of the principles behind the seat-to-head transmission curves, it is helpful to consider the theory of a simple vibration system consisting of a mass isolated from a vibrating base by a spring as shown in Fig. 2. If the base is caused to vibrate vertically with amplitude y_2 at frequency f, then, after equilibrium has been reached, the mass supported on the spring will vibrate at frequency f with amplitude y_1 (Kimball 1932, p. 107), where

$$y_1=y_2\left[1-\frac{m(2\pi f)^2}{k}\right]^{-1}, \qquad (1)$$

y_1 = amplitude of vibration of mass in centimetres, y_2 = amplitude of vibration of base in centimetres, m = mass in g, f = frequency of vibration in c.p.s., k = elastic constant of spring in dynes cm^{-1}.

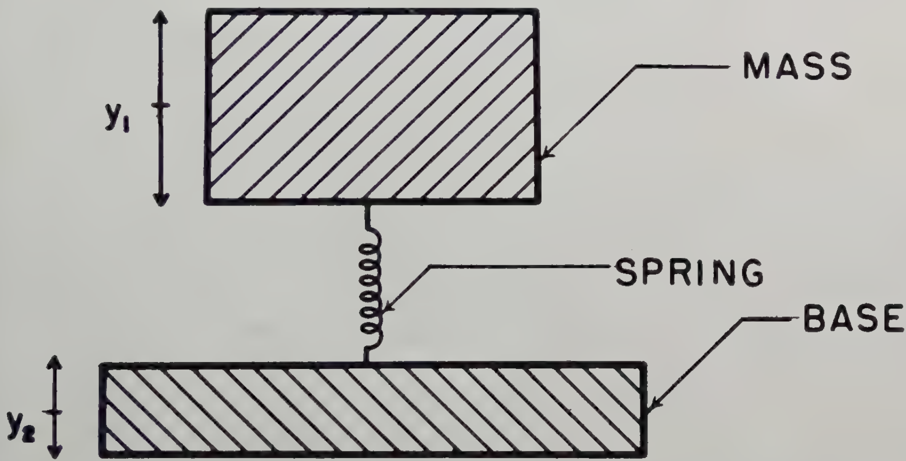

Figure 2. A simple problem in vibration isolation. A mass is isolated from a vibrating base by a spring.

The straightforward way of handling this sort of problem is by the solution of the appropriate differential equations (e.g. see Page 1935). A simpler method is available if these differential equations are linear, i.e. displacement is proportional to applied force for all springs in the system and all damping in the system (i.e. shock absorbers) opposes the motion by a force proportional to velocity. This simpler method is the solution by complex number theory for which simple rules are given by Kimball (1932, p. 36). Some methods of analysis of the vibration of non-linear systems are given by Stoker (1950). In general, non-linear systems probably are handled most easily by the use of analog computers.

For the simple vibration system of Fig. 2, the general shape of the vibration transmission curve can be seen by studying eqn. (1). Starting with 100 per cent transmission at $f=0$, increasing f causes increasing transmission until a peak is reached at the resonant frequency. Above the resonant frequency further increase in frequency causes transmission to decrease and approach zero asymptotically, as shown in Fig. 3.

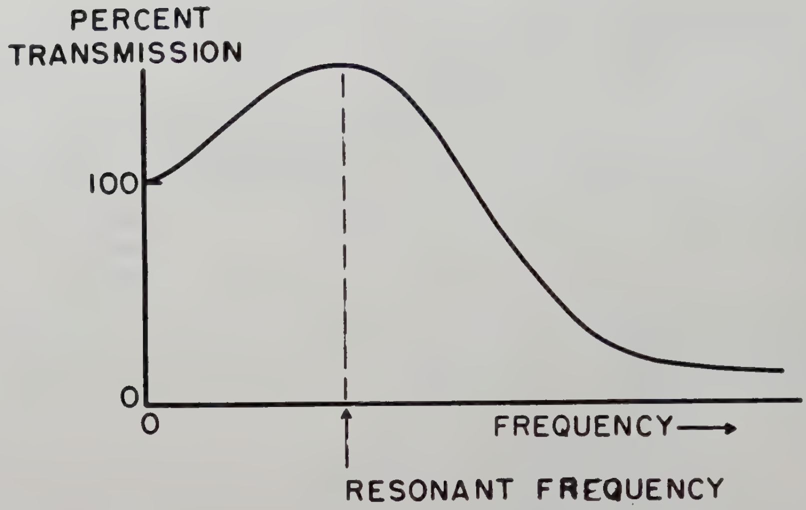

Figure 3. The general form of the curve of percent transmission of the amplitude of vibration from vibrating base to the mass, for the model shown in Fig. 2.

The experimentally determined seat-to-head transmission curves of the human subject have this same general shape, so it would seem that it might be useful to idealize the seated man by a mass on a spring as in Fig. 2. Since the spine and head are rigid compared to the buttocks, one might consider the buttocks to represent the spring upon which rests the mass of the seated man. The human system is actually more complicated than this since one or two minor resonances occur as well as the expected major one (Latham 1957, Dieckman 1958), which is due, at least in part, to relative movement of head with respect to shoulders. Also, it would seem likely that there is an appreciable amount of damping in the buttocks, which was not considered in the simple model. Serious departures from the predictions of the model may be expected with vibrations of amplitude greater than 2—3 cm, due to the elastic limits of the buttocks being reached.

The natural frequency of a mechanical system is defined as that frequency at which the system will vibrate if it is displaced from resting position and then suddenly released. For a system which may be described by linear differential equations, and with only a small amount of damping, the natural frequency is close to the resonant frequency (Page 1935). The natural frequency of the seated man for vertical displacements was determined by Coermann (1939) and Latham (1957) and was found to lie in the region of 3–5 c.p.s. This is close to the resonant frequencies of seated human subjects, and is in accord with expectations based on idealization of the model of Fig. 2.

Equation (1) provides a means of designing equipment to decrease the transmission of vibration from vehicle to man. In this discussion, the seated man is considered to be a mass, and the elasticity of his buttocks will be ignored, thus simplifying the problem so that the principles may be demonstrated with a minimum of mathematics. If a spring or similar device is put between the man and vehicle, then, by inspection, eqn. (1) shows that for any given frequency, the percentage transmission from vehicle to man may be made as small as desired simply by choosing a sufficiently small value of the spring

constant (k), i.e. by making the spring (or cushion) sufficiently soft. From eqn. (1), it can be seen that this also has the effect of lowering the resonant frequency. If a shock absorber (damping) is put in parallel with the spring, the height of the resonance peak may be decreased at the expense of increased transmission at higher frequencies. The point to be emphasized is that man may be shielded from vibration to any extent desired simply by mounting him on a spring or equivalent device.

Although it is possible to decrease the amplitude of vibration of the man to as near zero as desired, it is often unwise to do so, because, if a man is prevented from vibrating there is relative vibratory motion of the man with respect to the vibrating vehicle. This means that the controls vibrate with respect to the man, which may be expected to decrease the precision of his manual control movements and to interfere with his ability to read his instrument panel. In any given practical situation, it will be necessary to make some compromise between decreasing the vibration of the man and increasing the relative vibration between man and vehicle.

§ 3. Harmful Effects of Vibration

The best known effects of vibration on man are the nausea, vomiting and/or dizziness of motion sickness (reviewed by Steele 1955) which, in large part, result from stimulation of the vestibular apparatus of the inner ear. More serious vestibular effects are seen in some of the monkeys subjected to vertical vibration of $\frac{1}{4}$ or $\frac{1}{2}$ in. amplitude at 10 c.p.s. (Riopelle *et al.* 1958). Microscopic examination of the vestibular apparatus in these animals revealed damage consisting of detachment of the otolithic membrane (Riopelle *et al.* 1958). However, symptoms resembling motion sickness sometimes occur without vestibular stimulation, since a subject at rest can develop these symptoms from watching a moving object (Vogel 1931). Some of the patterns of motion known to cause motion sickness are discussed by Steele (1955).

Head-to-seat vibration has been observed to cause extensive lung damage (intra-alveolar haemorrhage) in mice (Roman 1958), cats (Fowler 1955), and monkeys (Riopelle *et al.* 1958), although only minimal damage to the heart was found. Fairly severe anterior chest pain occurring within 25 sec of the onset of vibration has been noted in man subjected to vertical vibration of approximately 0·15 in. amplitude at frequencies of 8–15 c.p.s. (White and Mozell 1958). It would seem reasonable to suppose that the chest pain in man might mark the beginning of lung damage of the type seen in animals.

Severe vibration in mice (Roman 1958) and monkeys (Riopelle *et al.* 1958) has been observed to cause intra-abdominal damage consisting of intra-peritoneal haemorrhages, mesenteric tears, and intestinal intussusception (in which a portion of intestine slides within the next adjacent portion). It is possible that the rectal bleeding seen in one human subject after 15 min of vibration at 20–25 c.p.s. and 0·17 in. amplitude (White and Mozell 1958), and the constipation seen in several subjects at 8–15 c.p.s. at 0·15 in. amplitude for $2\frac{1}{2}$ min (White and Mozell 1958) might mark the onset of development of some pathology such as this.

Vibration has been shown to affect visual acuity adversely. For example, when a man sits on a vertically vibrating shake-table, it has been found that

there is decreased ability to read numbers which were stationary relative to ground, i.e. did not vibrate (White and Mozell 1958). Increasing the frequency of vibration from 8 to 23 c.p.s. markedly impaired this type of performance but doubling the amplitude from 0·025 in. to 0·05 in. caused no detectable effect.

Vibration has produced various other types of damage to man and animals. One monkey developed brain haemorrhage (a subdural haematoma) following vibration (Riopelle *et al.* 1958). Several human subjects exposed to vertical vibration of 8–15 c.p.s. at 0·15 in. amplitude for $2\frac{1}{2}$ min were found to have small amounts of blood in the urine (White and Mozell 1958) which indicated that there was some sort of damage to some part of the urinary tract. The manual use of various vibrating tools has caused damage to the hands (Giullemin and Wechsberg 1953). Vibration of monkeys has been shown to cause a variety of non-specific stress effects, characteristic of the General Adaptation Syndrome of Selye (Selye 1950). These changes include an increase in the blood neutrophil count (Riopelle *et al.* 1958, Cope and Polis 1957), atrophy of lymph nodes (Riopelle *et al.* 1958) and increase in blood transaminase levels (Cope and Polis 1957). Various aeroplane pilots, with whom the author has talked, reported feelings of anxiety when flying in situations where the plane is subjected to excessive vibration. It is the author's impression that at least some of this is due to a fear of losing control of the plane.

Goldman (1948) made a tabulation of the frequencies and amplitudes of vibration that human subjects called unpleasant (discomfort threshold) or that subjects refused to tolerate (tolerance threshold). This study was a

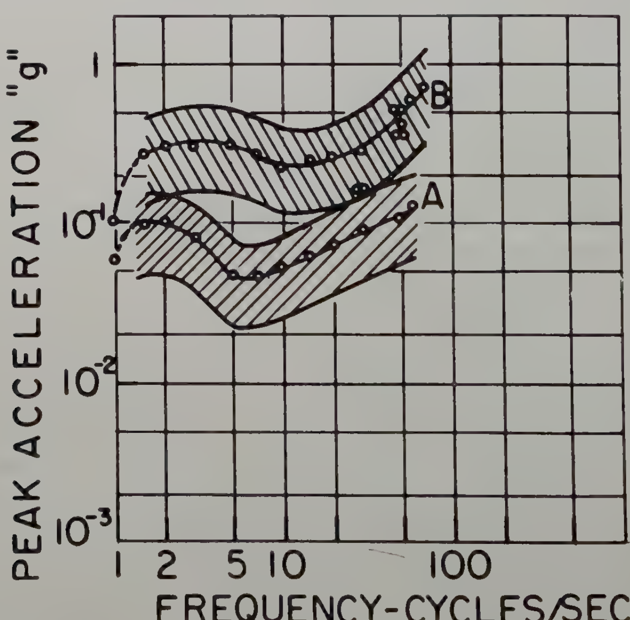

Figure 4. Peak accelerations in g (1 g=980 cm sec^{-2}) of vibration that human subjects called unpleasant (discomfort threshold, curve A) or refused to tolerate (tolerance threshold curve B). Lines bounding the cross-hatched strip give an estimate of the standard deviation of these measurements. (After Goldman 1948.)

compilation of the experimental results of many different authors who used different durations and directions of vibrations. Goldman plotted amplitude, peak velocity, and peak acceleration against frequency for every experimental determination of each threshold. For both thresholds it was found that the peak acceleration was relatively independent of frequency in a range of 2–50 c.p.s. (Fig. 4). The discomfort threshold of peak acceleration is approximately 7×10^{-2} g ($1 \text{ g} = 980 \text{ cm/sec}^2$) and the tolerance threshold is in the region of 4×10^{-1} g.

A method of preventing vibration damage to the organs of the chest and abdomen of mice was developed at Wright Air Development Center (Roman 1958). Vibrating mice were photographed stroboscopically. With vibration in a head-to-foot direction, the abdominal wall vibrated in a front-to-back direction, but the abdominal organs vibrated in the head-to-foot direction out of phase with the rest of the animal, thus forcing the abdominal wall forward during the footward half of each cycle. Immobilizations of the abdominal wall by a plaster cast prevented the relative motion of the viscera, and also prevented the damage to the chest and abdominal organs which otherwise resulted. Similarly in man, chest pain due to vibration at 25 c.p.s. can be eliminated by the application of a whole body cast (Roman 1958). The use of an inelastic abdominal binder will also reduce the severity of this symptom (Roman 1958). At present, however, it would seem pointless to put casts on men since chest and abdominal symptoms due to vibration, to the author's knowledge, have never been reported in aeroplanes or in any other practical situation although observed on shake-tables.

§ 4. Relationship of Experimental Work to Practical Problems in Vibration

Does vibration actually occur in transportation equipment at a high enough level to affect operators adversely ? In aeroplanes, at least, the vibration levels are sometimes within the region of discomfort and tolerance thresholds described by Goldman. This statement is based on U.S. Air Force vibration measurements in a variety of jet and propeller driven planes and helicopters (Getline 1955). Of the various symptoms ascribable to vibration that have been reported by operators of transportation equipment, motion sickness is, of course, the most common. Anxiety and fatigue are sometimes reported as occurring due to vibration, but it is always difficult to determine with any certainty the causes of this kind of symptom. The chest and abdominal symptoms which have been induced by vibration on shake-tables, to the author's knowledge, have never been reported by the operators of transportation equipment. This might be related to the fact that the vibration is largely below 5 c.p.s. in frequency whereas human shake-table studies have mostly been concerned with the higher frequencies. It is in the region below 5 c.p.s. that more work is needed.

It would seem appropriate to emphasize here the difficulties involved in studying the effects of vibration on performance. It is usually impossible to extrapolate from one type of performance to others, because of complex man–machine resonances which are specific for the mechanical and control

characteristics of the system. Hence, in vibration studies, it is unusually important that the set-up used for experimental study duplicates closely in all mechanical characteristics the practical situation about which information is needed.

§ 5. Some Methods of Vibration Protection

The common method of protecting man from vehicular vibration is by mounting him on a spring or equivalent device, such as an elastic cushion. By the methods described earlier in this paper, such a device can be designed so that for any given frequency, the transmission of vibration from vehicle to man is as small as desired. It should be remembered however that the vibration transmission characteristics are dependent upon the weight of the man sitting on the device.*

Seat cushions can be used as vibration shielding devices if their elasticity and damping constants are properly chosen. Polyurethane foam cushions can be made in a range of values of these constants by varying the proportions of the chemical ingredients used.

Another method of decreasing the transmission of vibration from the vehicle to the man's body is simply to have the man in the standing, rather than in the sitting position, since this has been shown to decrease the vehicle-to-head transmission (Coermann 1939). The transmission can be further decreased considerably by keeping the knees slightly bent while standing, or by standing on tiptoe (Müller 1939).

However, it should be emphasized again that in many practical situations, there is a serious question as to the desirability of placing vibration shielding between man and vehicle. When the man is shielded from vibration but the vehicle continues to vibrate, the result is a vibration of the vehicle with respect to the man which may be expected to interfere with manual control movements and with the acuity of vision for the instruments. In any given situation, one must choose the optimum compromise between vibration of the man and vibration of the vehicle relative to the man. This problem may be circumvented by mounting the most important controls on the seat. Thus, the man, the seat, and the controls as a unit, would be mounted on a spring or similar device thus preventing motion of the controls relative to the man. This arrangement has not actually been used to the author's knowledge. The same advantages as above may be obtained by shielding the entire vehicle from vibration, e.g. by rubber tyres, springs, better aerodynamic design, etc. Sometimes this may, of course, be a formidable engineering task.

An additional approach to the problem of vibration protection is the training of the operator, since the detrimental effects of vibration on performance might be considerably alleviated by proper training. It is reasonable to expect that a pilot might learn to anticipate man–machine resonance effects and to prevent them by changes in manual responses. Confidence gained through this type of training might prevent the anxiety which would otherwise occur.

* A seat utilizing the above principles is available commercially from the Bostrom Corporation Milwaukee, Wisconsin. It uses rubber torsion bars as a spring, with adjustment of the elastic characteristics to suit the weights of different pilots. The resonant frequency of the man–seat combination is said to be approximately 1·5 c.p.s. at which frequency the vibration amplitude of the vehicle is said to be amplified by about 125 per cent.

Les mouvements oscillatoires des véhicules en marche entrent dans le cadre des vibrations. La principale composante linéaire sinusoïdale de ces mouvements est habituellement orientée verticalement et de fréquence comprise entre 0 et 50 cps. Un organisme humain ou un animal soumis aux vibrations peut présenter une variété de symptomes et de lésions anatomiques. Ces effets peuvent être atténués en protégeant l'opérateur de la transmission des vibrations du véhicule. Une protection excessive n'est pas souhaitable en ce sens qu'elle exagère les déplacements relatifs de l'opérateur par rapport au véhicule et que, de ce fait, elle peut éventuellement provoquer une détérioration des performances. L'article passe en revue les notions de physique relatives à la protection contre les vibrations. Des procédés ce protection utilisables pour l'homme sont décrits et un dispositif couramment fabriqué est signalé.

Verf. diskutiert die Wirkung von Fahrzeug-Schwingungen auf den Fahrzeug-Führer. Die vorherrschende lineare sinusähnliche Komponente der Fahrzeugbewegung liegt gewöhnlich vertikal und hat Frequenzen zwischen 0 und 50 Hertz. Mechanische Schwingungen können Mensch und Tier in der verschiedensten Weise beeinflussen und anatomisch schädigen. Diese Wirkungen können durch Dämpfung der auf den Menschen übertragenen Schwingungen vermindert werden. Uebermässige Dämpfung in dem Sinne, dass eine starke Bewegung des Fahrers relativ zu der des Fahrzeuges entsteht, ist unerwünscht, da sie die Leistung des Fahrers beeinträchtigen könnte. Die physikalische Theorie für die Konstruktion von Dämpf-Einrichtungen wird umrissen. Die verfügbaren Wege zur Dämpfung der Schwingungen eines Fahrzeug-Führers werden besprochen.

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AN EXPERIMENT ON THE ASSESSMENT OF BRIGHTNESS UNDER 'FREE-CHOICE' AND 'FORCED-CHOICE' CONDITIONS BY A GROUP OF OBSERVERS

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An experiment is reported in which thirty-four subjects simultaneously made a series of assessments of the subjective brightness of a test patch in dark surroundings, indicating their estimates by the assignment of numbers chosen by themselves. Estimates made under these 'free-choice' conditions gave a relation between luminance and subjective brightness closely corresponding to the law previously found to relate sound energy level to subjective loudness.

When the subjects were given stated numbers to be assigned to the highest and lowest luminances, the relation was distorted but apparently not basically changed. The results can be interpreted as a demonstration that, under the experimental conditions, a basic relation exists between subjective brightness and the luminance of the stimulus which is distorted but not wholly suppressed when false information is given during its determination.

An opportunity arose to obtain assessments of brightness under controlled experimental conditions by thirty-four observers simultaneously. The subjects were all either architects or senior civil servants from the Architects and Building Branch of the Ministry of Education. None of the observers had made brightness judgments of this kind before.

The experiment consisted of the judgment by all the observers simultaneously of the subjective magnitudes of each of a series of ten luminances presented in random order.

The test patch consisted of circular opal diffusing screen 5 in. in diameter and illuminated from behind by an incandescent filament lamp. The voltage applied to the lamp could be varied in such a way as to give a range of luminance to the test patch from 0·4 ft lamberts to 10 000 ft lamberts. The test patch was screened to avoid illuminating the surroundings. The surroundings were maintained at a level of approximately 0·1 ft lamberts throughout the experiment. Ten fixed values of luminance were chosen as the test values, and these were presented in the following random order : 3·6, 290, 2600, 0·4, 880, 11, 98, 1·2, 7900 and 32 ft lamberts.

The average viewing distance was approximately 20 ft. The nearest observers were seated about 10 ft from the screen and the furthest about 30 ft. The solid angles subtended by the screen at these distances were $13{\cdot}6 \times 10^{-4}$ steradians (10 ft), $3{\cdot}40 \times 10^{-4}$ steradians (20 ft) and $1{\cdot}51 \times 10^{-4}$ steradians (30 ft).

The observers were briefed before the experiment commenced but were given the least information necessary to enable them to make the judgments. Each observer was given a piece of paper on which the numbers 1–10 were printed and space provided for him to record his judgments. Figure 1 shows a typical observation sheet filled in by one observer.

For the first stages of the experiment the observers were asked to record the subjective magnitude of each of the luminances presented. They were

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Presentation Number	A	B	C
1	100	5	5
2	120	7	7
3	400	18	15
4	1	3	3
5	300	10	10
6	50	5	4
7	200	7	5
8	50	3	3
9	1000	20	20
10	100.	7	7

Figure 1. Example of answer sheet.

asked to express the magnitude as a number and to make this number bear some relation to their judgment of subjective brightness. They were allowed to choose any number they pleased provided that a bright patch was given a high, and a dull patch a low number. Apart from this no restriction was placed on them as to the numbers they should choose. They were not aware whether the first luminance presented to them was in fact one of the higher or one of the lower in the available range. They were asked to record their assessment in the column C of the three columns given to them. No comments were made by the subjects, and no protests at the difficulty or impossibility of the task (as would probably have been made by scientifically trained subjects).

Each luminance was then presented in the random order previously determined, and observations were made simultaneously by all thirty-four observers but without collusion. At the end of this part of the experiment they were asked to fold column C back so that they could not see what numbers they had chosen.

The second stage of the experiment, which then followed, was exactly the same as the first, with the difference that the observers had the highest and the lowest luminances shown to them before the experiment started. They now had an idea of the total luminance range available, and so could estimate the magnitude of the first luminance presented in accordance with their knowledge of this range. The experiment then proceeded exactly as for the first part, the observers recording their chosen magnitudes in column B.

For the third stage the observers were asked to fold back the paper again so that only column A was available. They were now told to assign the number 1000 to the highest luminance, which was then shown to them, and the number 1 to the lowest, which was next shown to them, but not to write anything down before the test run. It was interesting that when these numbers were announced several of the observers protested against the choice. They were, however, persuaded to continue with the test. The luminances were then again presented in the same random order. The observers were not told when either the highest or the lowest luminance (to which the numbers 1000 and 1 had previously been assigned) were being shown.

Results

Figures 2, 3 and 4 show the results plotted on a log–log scale of luminance and brightness magnitude. The brightness scale represents the numbers which the subject assessed as those applying to the various test luminances. The order of presentation of these luminances is shown on the ordinate scale. The median value and inter-quartile ranges of each brightness magnitude estimation are given.

The medians are seen to lie fairly well on a straight line of slope approximately 0·3. This is the slope which had been found previously (Hopkinson 1956) for a series of similar judgments obtained by a limited number of observers under more closely controlled experimental conditions. A straight line has been drawn through the points to give the best fit to a relation $M = KL^{0\cdot 3}$, where M is the magnitude of brightness sensation as judged by an observer and L is the physical luminance of the test patch. This is the relation, found by Stevens (1956) and others, between loudness and sound energy level, and it is of interest that these results show certain affinities with the loudness scales.

The inter-quartile ranges are large. This simply means that the observers chose a wide range of numbers in order to express their estimates of the subjective brightness. The actual values chosen, are, however, in this case of secondary interest, the important matter being the relation between the numbers chosen and the corresponding physical luminances.

Figure 3 is seen to give essentially the same result as that given in Fig. 2. The information which the subjects were given before the second test, that is, the presentation of the highest and the lowest luminances which were to be seen on the run which was to follow, does not appear to have affected their judgment in any way.

It is, however, an entirely different story which is told in Fig. 4, where the observers, instead of being allowed freely to choose the numbers they would use, were told that they must denote the highest and lowest luminances

by the numbers 1000 and 1 respectively. This instruction has clearly upset their judgment. It is interesting to note, however, that if the magnitudes given to the highest and lowest luminances are neglected, the medians lie close to a slope of 0·3 as in the 'free-choice' conditions which led to the results shown in Figs. 2 and 3. The actual numbers chosen on this third test were, however, very much higher. An attempt appears to have been made to choose numbers consistent with the 1000 given to the highest luminance. The attempt has, however, been almost abandoned to link them with the number 1 given to the lowest luminance. Although the majority of the observers did recognize the patch when it came and gave it the demanded number 1, several did not and assigned it a higher number.

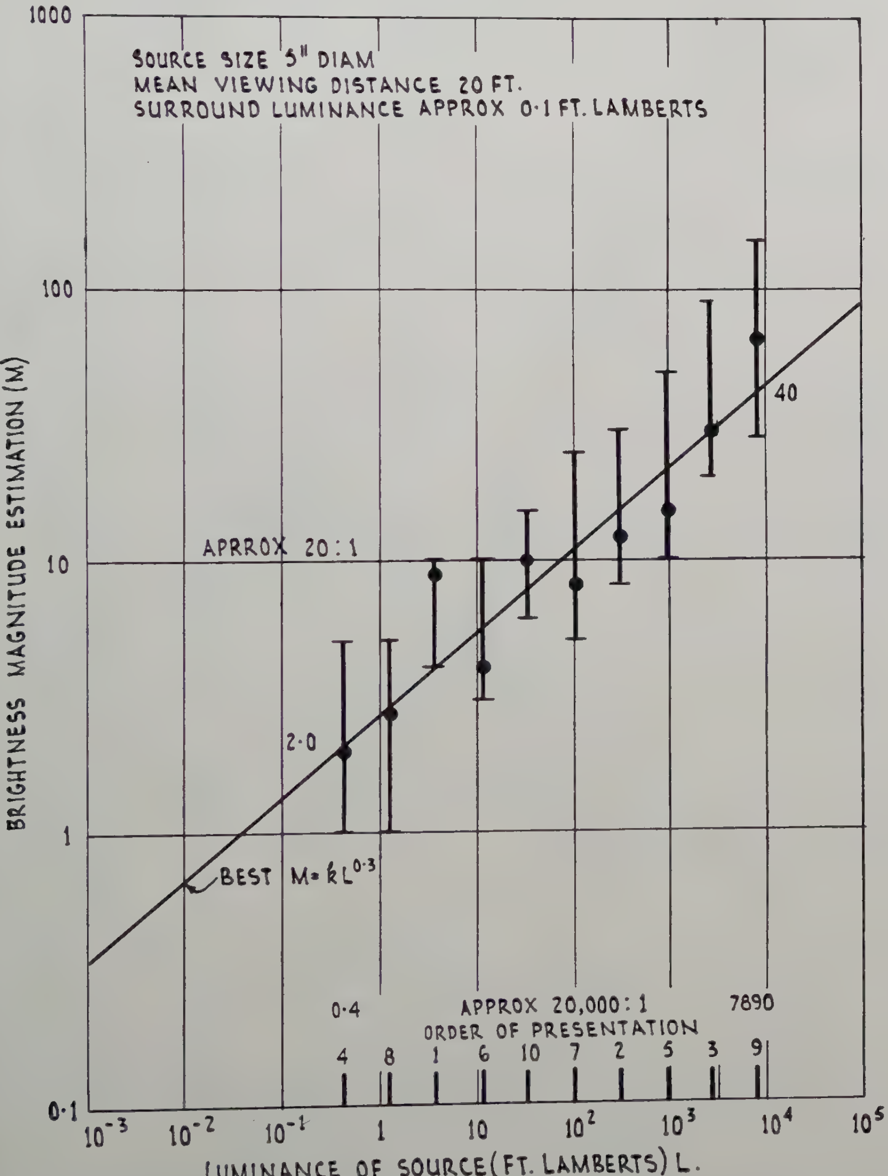

Figure 2. Medians and interquartile ranges. Subjects given free choice and no indication of limits.

An interpretation of the results shown in Fig. 4 would be that the basic, relation (for the given experimental conditions) between luminance and subjective brightness has to some extent superposed itself over the false relation introduced by the 'forced-choice' of numbers for the highest and lowest luminances. Memory does not appear to have played much part because all the numbers chosen in this last test were very much higher and quite different from those in the previous two tests.

In Figs. 2 and 3 a range of more than 20 000 to 1 in physical luminance is represented by a range of only 20 to 1 in estimated magnitude. It would have been interesting to see what would have been the result in the third stage

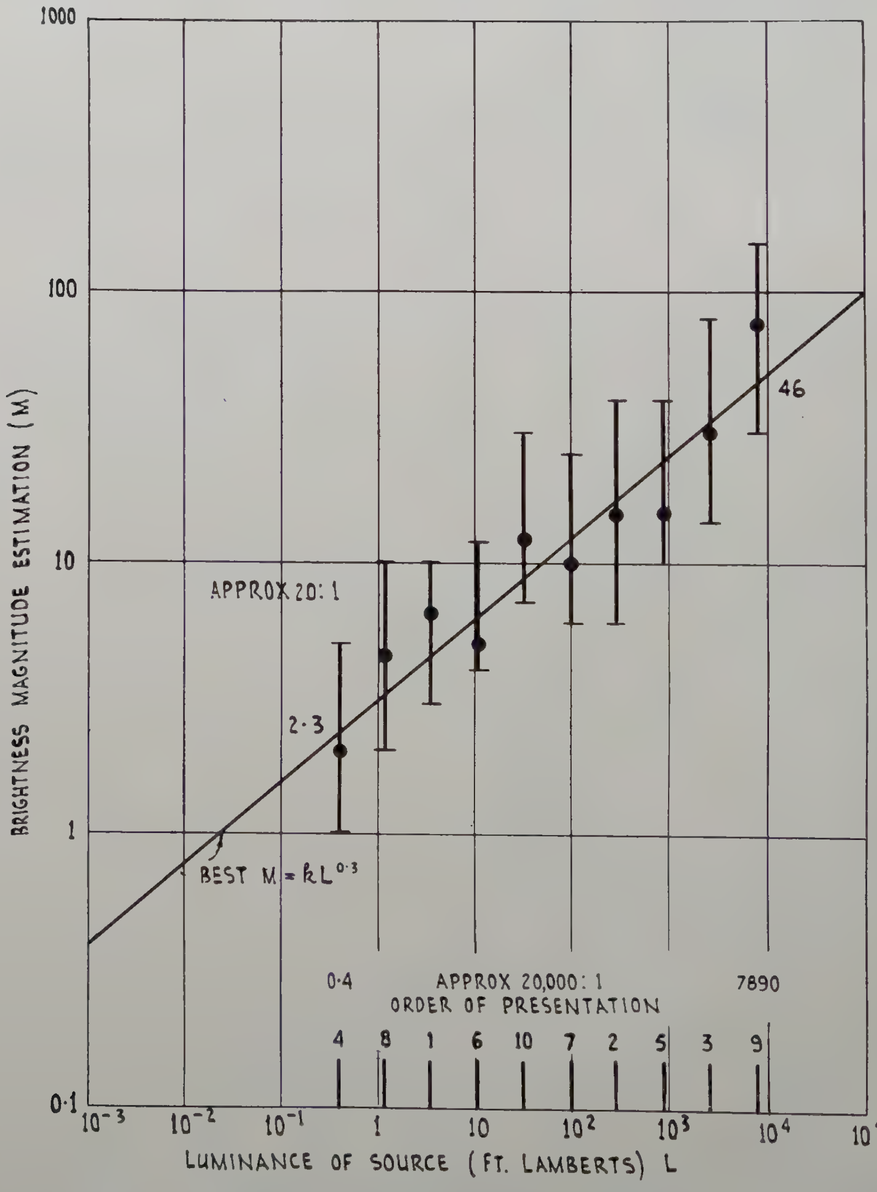

Figure 3. Medians and interquartile ranges. Subjects given free choice but initial demonstration of limits.

of the experiment if the number 20 had been allocated to the highest luminance instead of 1000. On this point it is worth noting that after the experiment was over the observers were asked to comment on the choice of the numbers 1 and 1000 for the extremes of the range provided. The comments were that the numbers expressed too wide a range. The experiment was actually conducted during the course of a lecture : while the rest of the lecture was continuing, the results were computed and presented to the audience at the end. The observers then agreed that the range of about 20 to 1 did in fact accord with what they would have estimated as being the subjective range of the brightnesses presented.

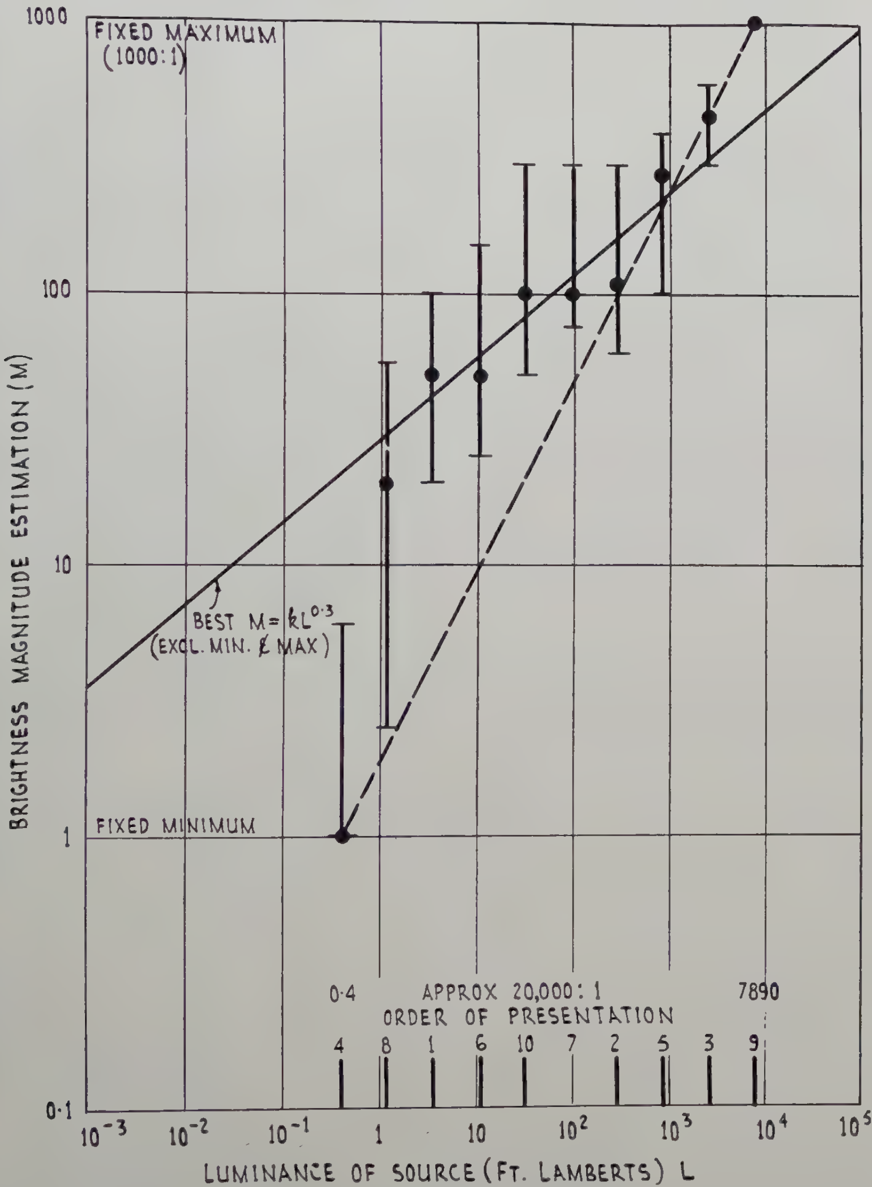

Figure 4. Medians and interquartile ranges. Subjects given initial demonstration of limits and asked to call minimum 1 and maximum 1000.

This experiment was conducted during the course of a lecture given to the Architects and Building Branch of the Ministry of Education, Chief Architect, Mr. A. Pott. Acknowledgments are made to the observers who participated so willingly in the experiment, and to Mr. J. Longmore who arranged the experiment and recorded the data. The paper is published by permission of the Director of Building Research and forms part of the programme of the Building Research Board.

On a rapporté concernant une expérience, dans laquelle on a demandé aux 34 sujets de se déclarer, en même temps, quant à la clarté d'une tache d'essai située dans des environs obscurs. Leur observations ont été faites et exprimées en des valences choisi par eux-mêmes. Les valences données sous ces conditions d'un choix libre ont produit une relation entre la force de luminescence et la clarté subi d'une façon subjective, relation qui a répondue d'une façon très précise à la loi—trouvée au préalable—de la relation de la force de son subie d'une façon objective et subjective.

Si on donna aux sujets des chiffres fixées, avec la tâche de les donner à la force de luminescence la plus haute ainsi qu'a la force la plus basse, puis la relation était dérangée mais pas changée d'une façon fondamentale. Les resultats peuvent être regardés comme demonstration que, sous des conditions experimentielles, une relation fondamentale entre la clarté qui est subie d'une façon subjective et le stimulus de la force de luminescence existe, relation qui est dérangée mais qui n'est pas entièrement supprimée si, pendant sa détermination, on donne des informations qui ne sont pas justes.

Es wird über ein Experiment berichtet, in dem 34 Versuchspersonen gleichzeitig eine Reihe von Angaben über die subjektiv empfundene Helligkeit eines Testfleckes in dunkler Umgebung machten ; sie machten ihre Angaben in selbstgewählten Zahlenwerten. Die unter diesen Bedingungen freier Wahl geschätzten Werte ergaben eine Beziehung zwischen Leuchtstärke und subjektiv empfundener Helligkeit, die sehr genau dem früher gefundenen Gesetz des Verhältnisses von objektiver und subjektiv empfundener Lautstärke entsprach.

Wurden den Versuchspersonen festgelegte Zahlen gegeben, die sie der höchsten und niedrigsten Leuchtstärke zuzuordnen hatten, so war des Verhältnis verschoben, doch nicht grundsätzlich geändert. Die Ergebnisse können als Demonstration dafür gedeutet werden, dass unter den experimentellen Bedingungen eine grundlegende Beziehung zwischen der subjektiv empfundenen Helligkeit und dem Reiz der Leuchstärke besteht, die verschoben, aber nicht ganz unterdrückt wird, wenn während ihrer Bestimmung falsche Informationen gegeben werden.

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VISUAL AND TACTUAL JUDGMENTS OF SURFACE ROUGHNESS

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A laboratory experiment is reported in which skilled and unskilled subjects were required to make comparative judgments of surface roughness, by the use of visual or tactile cues or both, under five different inspection conditions. The small and, in most conditions, insignificant differences between skilled and unskilled subjects, and the effects of changes in the inspection conditions, are discussed in relation to the industrial problem which prompted the investigation.

§ 1. Introduction

Some industries are fortunate in that they use materials and processes which can be inspected objectively by, say, optical or electronic methods. Other industries must retain inspection methods which depend upon the subjective impressions of a skilled observer. The textile industry immediately comes to mind and, here, psychologists have given a great deal of thought to the problems which are involved in visual and tactual judgments of wool samples, etc. (Binns 1934, 1937, McKennell 1958, Stockbridge and Kenchington 1957). The woodworking industries have many similar problems which, however, have received relatively little attention. The assessment of surface roughness is one of their major problems, due to the inconsistency of the material and the unsuitability of simple objective measures. The problem is not only the aesthetic one of obtaining surfaces which are good to look at, but the technical need to obtain a surface which is receptive, over its whole area, to a finishing material of some kind. Surface judgments must be quite critical if the finish is to be consistent and durable.

In the industry these judgments can be made by the use of both visual and tactile cues. Large surfaces must first of all be judged for consistency of appearance, which involves comparative judgments. The final surface must be matched against a remembered standard, which involves an absolute judgment. The accuracy with which the judgment is made can vary considerably between individuals and is known to suffer from diurnal and day-to-day fluctuations. This increases the difficulty in matching finished surfaces. Speed and accuracy of performance are vital in this task which, under existing conditions, is often the bottle-neck in a line of machine-paced operations. Therefore an improvement in human performance would reduce overall operating times and allow machines to be worked with greater efficiency.

An investigation of this situation was undertaken at the request of the Furniture Development Council. This paper reports an initial study of comparative judgments, which were thought to be more important than absolute judgments in this situation where the final standard of smoothness was limited by the characteristics of the smoothing medium. The experiment was designed in an attempt to supply answers to the following questions:—

1. Under present conditions, which sensory modality is being used to the greater extent, by skilled operators, in the formation of a judgment ?
2. Can existing inspection conditions be improved ?
3. How does the performance of skilled subjects differ from that of unskilled ?

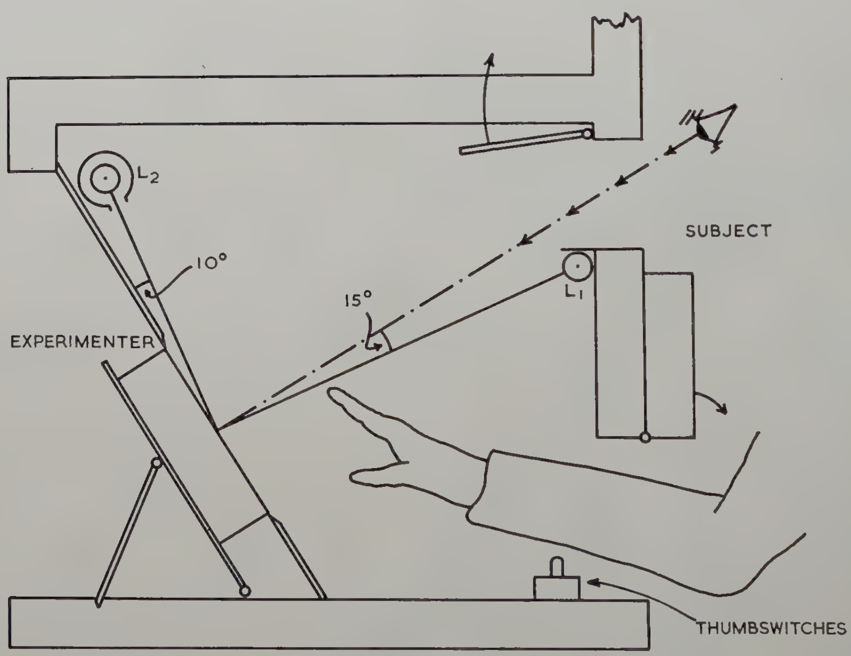
§ 2. Method

The first requirement was an objective scale of roughness. Nine flat wooden surfaces, about 6 in. square, of the same colour and free from identifying grain markings, were worked to different degrees of roughness. Nine readings of irregularity were taken at different positions on each surface, by means of a Talysurf Model II electronic instrument. The surfaces were then graded on the basis of the average of these measures, which are shown in Table 1. The result was not an equal-interval scale but there were definite

Table 1. The objective scale of roughness

Surface	A	B	C	D	E	F	G	H	I
Average Irregularity in micro-in.	375	362	349	347	297	269	205	162	134

differences between adjacent surfaces in the range. The experimental design required the subjects to make their judgments by the method of paired comparisons. Subjects were asked to select the rougher of each pair in the 36 possible combinations.



Apparatus for paired comparisons of surfaces :
L_1 = Normal lighting } 60 w lamps.
L_2 = Oblique lighting }

The figure shows a cross section through the apparatus. The two surfaces which were to be compared were enclosed, side-by-side, in a light-tight box on one side of a screen. The subject sat on the other side of the screen and

viewed the surfaces through an eye-level slot, which brought his line of sight approximately at right angles to the surfaces and 12 in. from them. The surfaces were illuminated by projecting light on to them from L_1, (normal lighting) or from L_2 (oblique lighting). Both L_1 and L_2 were strip filament lamps of 60 w. The intensity of illumination was estimated to be equivalent to that which was observed to be usual in the industry. The distances of L_1 and L_2 from the surfaces were adjusted to give equal intensities of illumination at the centre of each surface in both normal and oblique lighting. The viewing slot was covered between trials by a shutter, which was translucent to minimize the effects of adaptation to varying light intensity.

For tactual judgments a lower shutter could be opened to permit the insertion of both hands.

The subject indicated his choice of the rougher surface by depressing a switch beneath his left or right foot. These switches were connected to a buzzer circuit through a two-way selector switch, which was set by the experimenter to give a warning signal after each incorrect response. For visual inspections only, the opening of the shutter started a dekatron timer, which was stopped by either of the foot-switches to record response time. For tactual inspections only, the subject began his hand movements from a pair of thumb-switches, which were placed at such a distance from the surfaces that the subject could not both press the switches and touch the surfaces at the same time. The timer was started in these cases by releasing the thumb-switches and stopped by the foot-switches as before. When visual and tactual inspections were allowed, recording procedure followed that for visual inspection only and the subject rested his hands upon the thumb-switches until required.

Each subject made a set of 36 judgments under each of five different conditions :

(1) Visual judgment only, in oblique lighting (V(O)).
(2) Visual judgment only, in normal lighting (V(N)).
(3) Tactual judgment only, (T).
(4) Tactual judgment plus visual judgment in oblique lighting (V(O) + T).
(5) Tactual judgment plus visual judgment in normal lighting (V(N) + T).

Two groups of subjects were tested. Thirty-three naval ratings, who were not accustomed to making this kind of decision, made up the ‘ unskilled ’ group. The skilled group contained five men who were employed in a large furniture factory in direct connection with the inspection of surfaces, plus three research technicians who had been trained in the woodworking industries and were very frequently required to make judgments of this kind.

The subject was seated in front of the screen and the appropriate inspection condition was explained. Four practice comparisons were made to familiarize the subject with the range of roughness which was covered by the scale and the procedure for presenting each pair of surfaces. One complete test run of 36 comparisons followed. Knowledge of results was given after each comparison, to indicate correctness of response. The experimenter stated ‘ Yes ’ or ‘ No ’, as appropriate, in addition to the buzzer warning which followed incorrect responses. No indication of response time was given, although the subject knew that this was being recorded. All subjects were instructed to work as quickly as possible, consistent with accuracy. When

both visual and tactual inspections were allowed, the subject was instructed to use visual cues immediately the shutter was opened, supported by tactile cues in cases of doubt. Each subject was assigned at random one of the 120 possible orders in which the five conditions could be presented. The position of the rougher surface in each pair, relative to the subject, was also randomized. Unskilled subjects were given one condition per day for five consecutive days. Skilled subjects were given all five conditions on one day at intervals of 30 min (research technicians), or 60 min (industrial sanding machine operators).

§ 3. Results

3.1. *Percentage Error and Task Difficulty*

In order to relate the experimental results to the industrial task, errors of judgment in the five conditions were tabulated against task difficulty. This latter variable was measured in terms of the number of intervals between the surfaces being compared. For example, the extremes of the scale differed by 8 intervals. The errors of skilled and unskilled subjects are shown in Tables 2 and 3 respectively.

Table 2. Percentage error in judgments at different levels of task difficulty.

Skilled subjects : N=8

Inspection condition	Number of intervals between compared surfaces							
	1	2	3	4	5	6	7	8
Visual judgment (Oblique lighting)	10·9	—	—	—	—	—	—	—
Visual judgment (Normal lighting)	28·1	10·7	2·1	5·0	3·1	—	—	—
Tactual judgment	10·9	1·8	—	—	—	—	—	—
Visual + tactual judgment (Oblique lighting)	12·5	—	—	—	—	—	—	—
Visual + tactual judgment (Normal lighting)*	12·5	4·1	—	—	—	—	—	—

* One subject, who began the test with this condition, performed atypically here. He reported attempting to discriminate roughness on the basis of colour differences. His scores in this condition are excluded from the mean values in this and following tables, and his performance is discussed later.

Table 3. Percentage error in judgments at different levels of task difficulty

Unskilled subjects : N=33

Inspection condition	Number of intervals between compared surfaces							
	1	2	3	4	5	6	7	8
Visual judgment (Oblique lighting)	4·9	0·5	0·5	—	—	—	—	—
Visual judgment (Normal lighting)	27·3	14·3	8·6	3·0	—	—	—	—
Tactual judgment	18·2	5·2	1·0	—	—	—	—	—
Visual + tactual judgment (Oblique lighting)	8·7	—	—	—	—	—	—	—
Visual + tactual judgment (Normal lighting)	19·7	8·6	1·0	0·6	—	—	—	—

In the industrial task, differences in roughness between areas of the same surface are large at first, but become progressively smaller as the smoothing operation is carried out. Therefore the inspection task becomes progressively more difficult. In Tables 2 and 3, task difficulty increases as the rows are

followed from right to left. The 'final touches' of the industrial smoothing operation involve the comparison of surface areas which may differ in roughness by an interval which is equivalent to an interval of unity on the roughness scale in the present experiment. Tables 2 and 3 indicate that errors at this degree of sensitivity may be substantial.

3.2. *Sensitivity of Discrimination*

Frequency and magnitude of error were combined in a single measure of sensitivity of discrimination, in order to facilitate comparisons of the results of skilled and unskilled performances and to evaluate the inspection conditions. The following model, which is based on the industrial smoothing task, was set up to introduce the calculation of this measure : Suppose that an operator has two areas A and B, the roughness interval between them being 8 units, with A rougher than B. By smoothing A the operator can reduce the interval in steps of 1 unit. His task is to make a judgment at each step and to stop when A is first judged smoother than B. Suppose that he will certainly stop if he has reduced the interval to zero. Let the probability of stopping when the interval is r units be p_r. Then he stops at an interval of 8 units with probability p_8. He stops at an interval of 7 units with probability $(1-p_8)\,p_7$, and so on. He will stop at zero interval with probability

$$(1-p_8)(1-p_7)\ldots(1-p_1).$$

The average interval at which the operator stops may be called the 'average acceptable interval', (I_a), which can be calculated from :

$$I_a = 8\,.\,p_8 + 7\,.\,(1-p_8).\,p_7 + 6\,.\,(1-p_8)\,.\,(1-p_7)\,.\,p_6 + \ldots + 0\,;$$

I_a will be expressed in terms of the average interval of the original roughness scale. It can be used as a measure of the sensitivity with which the operator is able to discriminate between the roughness of areas A and B. Smaller values of I_a will indicate more sensitive discriminations. In order to fit the experimental results to the model it must be assumed that the operator makes each judgment independently of all previous judgments and makes errors (A smoother than B) with equal frequency for all pairs of surfaces of the same interval apart.

Mean values of I_a are given in Table 4. Two points about these values should be noted :

(i) *Differences between skilled and unskilled subjects:* Inspection of the individual scores of each group of subjects revealed some tendency for skilled subjects to discriminate roughness more sensitively than unskilled subjects in conditions V(N), T and V(N) + T, although the difference was not statistically significant. Now condition V(N) simulated industrial viewing conditions and the skilled subjects were accustomed to making tactual judgments. Therefore conditions V(N), T, and V(N) + T were regarded as 'familiar' to the skilled subjects. Conditions V(O) and V(O) + T were regarded as 'unfamiliar' to the skilled group, as the tactual judgment was used extremely infrequently in condition V(O) + T. Average values of I_a for 'familiar' and 'unfamiliar' conditions are shown in Table 5. The value of I_a (familiar) minus I_a (unfamiliar) for skilled subjects was 42 per cent smaller than for unskilled.

(ii) *Differences between inspection conditions:* It can be seen from Table 4 that in the case of single modality judgments, condition V(N) allowed only

Table 4. Average acceptable interval (I_a) expressed as a proportion of I, the average interval of the roughness scale.

Subject grouping	Inspection condition: Visual judgment (Oblique lighting)	Visual judgment (Normal lighting)	Tactual Judgment	Visual + Tactual Judgment (Oblique lighting)	Visual + Tactual judgment (Normal lighting)
Skilled (N=8)	0·109	0·724	0·145	0·125	0·196
Unskilled (N=33)	0·072	0·790	0·295	0·095	0·395

(i) Differences between skilled and unskilled subjects : The Mann-Whitney U test (see Siegel 1956), was applied separately to each condition. None of the differences was found to be significant.

(ii) Differences between inspection conditions : The two groups of subjects were considered separately and the Wilcoxon Matched–Pairs, Signed–Ranks test of significance (see Siegel 1956) was applied to the differences between all pairs of conditions. For skilled subjects, these differences were significant ($p=0·05$) only between V(O) and V(N), between V(N) and T, and between V(N) and V(O)+T. For unskilled subjects, differences were not significant between V(O) and V(O)+T and between T and V(N)+T. In all other cases the differences were significant beyond the $p=0·001$ level with the exception of that between V(O) and T, where $p=0·05$.

relatively insensitive discrimination of roughness. Judgments of skilled subjects were about equally sensitive in condition V(O) and in condition T, but tactual judgments by the unskilled subjects were not as sensitive as their visual judgments in condition V(O). When two sensory modalities were used in combination, the resulting discrimination was effected, on average, less sensitively than in the ' better ' modality alone, although the differences were not significant.

Table 5. Differences between 'familiar' and 'unfamiliar' conditions in terms of the calculated 'average acceptable interval'

	Skilled subjects*	Unskilled subjects
I_a (familiar)	0·355	0·493
I_a (unfamiliar)	0·117	0·084
Difference	0·238	0·409

* Only seven skilled subjects were included : see note to Table 2.

The difference between I_a (familiar) and I_a (unfamiliar) was significantly smaller ($p=0{\cdot}0038$) by the Mann-Whitney 2-tailed test.

3.3. *Response Time*

The mean judgment times are shown in Table 6. Total response times for tactual judgments included movement time from the thumb-switches to the surfaces. A separate estimate of this movement time was obtained from a test in which 10 subjects from the unskilled group each made 50 responses. The mean movement time was found to be 0·40 sec. This value was subtracted from total response time to give the actual judgment time shown in Table 6. Thus each tabulated time was measured from the initial reception of visual or tactile cues to the completion of a motor response. Two points may be noted about these times :

(i) The differences between skilled and unskilled subjects were in all conditions small and insignificant.

(ii) As between inspection conditions, V(O) was clearly the quickest and significantly faster than V(N) which was in turn quicker than T. Among the conditions in which both visual and tactile cues could be used, V(O) + T was not significantly longer than V(O), presumably because tactual judgment was seldom necessary in this condition. V(N) + T was however significantly slower than either V(N) or T and was in fact the slowest condition of all.

The effect of task difficulty upon the response times of skilled and unskilled subjects is shown in Tables 7 and 8. Task difficulty increases as the rows are followed from right to left, when the differences between the tabulated values in any column indicate the relative response times to be expected as the industrial smoothing task progresses.

§ 4. Discussion

A discussion of differences between skilled and unskilled subjects cannot be separated, entirely, from a consideration of the inspection conditions which were tested. Only conditions V(N), T and V(N) + T simulated the industrial task. Conditions V(O) and V(O) + T were both regarded as 'unfamiliar', as oblique lighting is not used in the industrial task and tactile cues were seldom used, during the experiment, with visual inspection in oblique lighting. The training which these skilled subjects have received would be expected to

Table 6. Mean response time (sec)

Subjects	Inspection condition: Visual judgment (Oblique lighting)	Visual judgment (Normal lighting)	Tactual Judgment	Visual + Tactual Judgment (Oblique lighting)	Visual + Tactual Judgment (Normal lighting)
Skilled (N=8)	0·96	1·60	1·72	1·09	2·00
Unskilled (N=16)*	0·96	1·32	1·47	0·95	1·50

* The times for only 16 subjects have been tabulated because of a fault in the timing apparatus which rendered the times for 17 subjects invalid.

(i) Differences between skilled and unskilled subjects: When each condition was considered separately, the response times of skilled subjects did not differ significantly from those of unskilled subjects. No difference was found between skilled and unskilled subjects when a score of R.T. (familiar) minus R.T. (unfamiliar) was calculated.

(*ii*) Differences between inspection conditions: For both groups of subjects, response times in condition V(O) were significantly less than those in condition V(N), ($p=0{\cdot}01$ Wilcoxon test), and response times in condition V(N) were significantly less than response times in condition T, ($p-0{\cdot}05$). Response times in condition V(O)+T were not significantly longer than those in conditions V(O) or T. Response times in condition V(N)+T were significantly longer than response times in condition V(N) and condition T, ($p=0{\cdot}05$).

enable them to discriminate roughness more sensitively than unskilled subjects in ' familiar ' conditions. In fact the observed difference between groups was extremely small and appeared to be centred mainly on the tactual judgments, although even in this case it was not significant. This is perhaps not altogether surprising, when it is considered that judgments of roughness must be made quite frequently in everyday life, even by ' unskilled ' subjects.

Table 7. Response times (sec) at different levels of task difficulty

Skilled subjects : N = 8

Inspection condition	Number of intervals between compared surfaces							
	1	2	3	4	5	6	7	8
Visual judgment (Oblique lighting)	1·52	0·98	0·84	0·72	0·71	0·73	0·67	0·68
Visual judgment (Normal lighting)	2·00	2·05	1·50	1·36	1·22	1·09	1·12	1·02
Tactual judgment	3·05	2·23	1·33	1·08	1·04	1·17	1·00	0·93
Visual + tactual judgment (Oblique lighting)	1·66	1·16	0·86	0·89	0·74	0·74	0·75	0·64
Visual + Tactual judgment (Normal lighting)	2·79	2·20	1·89	1·67	1·40	1·58	1·35	1·44

Table 8. Response times (sec) at different levels of task difficulty

Unskilled subjects : N = 16

Inspection conditions	Number of intervals between compared surfaces							
	1	2	3	4	5	6	7	8
Visual judgment (Oblique lighting)	1·40	1·03	0·83	0·78	0·72	0·75	0·68	0·70
Visual judgment (Normal lighting)	1·69	1·54	1·29	1·16	1·01	1·04	0·89	0·85
Tactual judgment	1·93	1·63	1·51	1·22	1·14	1·11	1·03	1·07
Visual + Tactual judgment (Oblique lighting)	1·40	1·11	0·81	0·73	0·70	0·70	0·64	0·66
Visual + Tactual judgment (Normal lighting)	1·99	1·85	1·41	1·25	1·08	1·03	1·06	0·88

Training in the comparative judgment of roughness appears, therefore, to enable very little improvement to be made in the level of performance which has been achieved by the average adult in the acquisition of everyday skills. With respect to the tactual judgment, this finding agrees with that of Binns (1934, 1937), who observed that unskilled subjects were able to make tactual judgments of wool tops with remarkable accuracy, although they were not so proficient in visual judgements.

The results of visual judgments in oblique lighting show that extremely efficient use can be made of the visual cues provided by shadowing surface irregularities. On the evidence of introspective reports from skilled subjects, this was due to the fact that the shadows were directly related to surface roughness and judgment was, to a great extent, independent of surface colour. In normal industrial lighting, (simulated by condition V(N)), surfaces of different roughness appear to an observer to differ only in shades of colour. As there may be a slight difference in the colour of the two surfaces in any case, colour is an unreliable guide to differences in roughness. The inadvisability of attempting to discriminate roughness by the use of colour differences is illustrated by the results of one skilled subject in condition V(N) + T who had this condition as his first. This subject was confident that the roughness scale

could be ranked by colour and incurred a 40 per cent error. This procedure was peculiar to this one subject, who after the unsuitability of this method was pointed out performed typically in the other conditions.

Definite instances of conflict between visual and tactile information were observed, when combined visual and tactual judgments were made. Some subjects reported that, on some occasions, a completely confident judgment could not be made from the initial visual inspection but, when a tactual inspection was carried out, the result was opposed to the tentative visual judgment. In these cases the subject was forced to accept one of two conflicting reports. The results indicate that, in this situation, performance tended to deteriorate to a level below that which would have been expected from the use of one sense only. It is not immediately clear why this should have been so but it is possible that, in this more stressful situation, some subjects were prepared to guess the result of the comparison, in order to obtain a short response time.

If the experiment accurately reflects existing industrial conditions, the visual cues derived from normal lighting are inadequate for the required level of roughness discrimination. As the task appears to be performed with a fair degree of accuracy by skilled operators in the industry, it would follow that their judgments derive mainly from tactile information. It seems likely that a considerable saving in time, and a possible improvement in sensitivity of discrimination, would be gained by using oblique lighting and allowing visual judgments only. However, in view of the possibility of visual fatigue after prolonged inspection and the impossibility in practice of preventing ‘ handling ’, the advantages to be gained by allowing both visual and tactual inspections may outweigh the disadvantages of increased inspection time and a possible decrease in sensitivity.

Grain configuration and wood dust undoubtedly would reduce the high level of efficiency of visual judgment in oblique lighting, which has been found under ideal conditions. However, the tactual judgment is not entirely unaffected by these factors so that the difference between visual and tactual judgments may in fact be changed very little under industrial conditions.

§ 5. Conclusions

(*a*) Under present industrial conditions, skilled operators must perform sensory discriminations of surface roughness by the almost exclusive use of tactile cues, due to the inadequacy of visual information.

(*b*) If oblique lighting is used to illuminate a surface, very efficient use can be made of the grain–shadowing effect. This visual information can be used by skilled subjects as efficiently as tactile information, and much more rapidly.

(*c*) Discrimination of surface roughness by subjects who are skilled in this task under industrial conditions is slightly more sensitive than that by subjects who are unskilled, when the inspection conditions are familiar to the skilled subjects. When surfaces are illuminated by oblique lighting (which improves the overall level of roughness discrimination), the training which the skilled subjects have received does not assist them to discriminate roughness more sensitively, or rapidly, than unskilled subjects.

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Au cours d'une expérience de laboratoire, on a demandé à des sujets, d'une part entraînés au préalable, d'autre part inexpérimentés, d'émettre des jugements comparatifs de la rugosité des surfaces, en se servant d'indices uniquement visuels ou tactiles ou des deux à la fois, dans cinq conditions d'inspection différentes. Entre sujets entraînés et sujets inexpérimentés, de petites différences, significatives dans la plupart ces conditions, sont apparues, ainsi qu'une influence des changements des conditions d'inspection. Ces résultats sont discutés en rapport avec le problème industriel qui a suscité la recherche.

Es wird über Laboratoriums-Versuche berichtet, in denen geübte und ungeübte Personen die Rauhigkeit einer Oberfläche unter 5 verschiedenen Prüf-Bedingungen vergleichsweise visuell oder taktil, oder auf beiden Wegen zugleich, zu beurteilen hatten. Die geringen und meist nicht signifikanten Unterschiede zwischen geübten und ungeübten Personen, und die Wirkung von Aenderungen der Prüf-Bedingungen werden in Bezug auf das industrielle Problem, das der Anlass dieser Untersuchung war, diskutiert.

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ACCURACY AND SPEED OF TACTUAL READING: AN EXPLORATORY STUDY

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The study reported here was an attempt to determine the ability of individuals to read words presented tactually. This information has practical implications for military or other situations where the weapon or machine operator may be required to operate his equipment in the absence of visual cues. Six subjects made a total of 540 identifications of words ranging from two to seven letters in length. The average time of performance ranged approximately linearly from 5·5 sec. for two letters to 24·5 sec. for seven letter words. Practice with 90 words during a one hour session resulted in an overall improvement of 29 per cent in time of response. It was also indicated that repeated practice with the same words would reduce the time of performance even further. It is concluded that the time required to impart this type of information to an operator via the touch sense makes this technique practical for most situations where visual cues are precluded.

The accuracy of responses was 97·2 per cent. This high degree of accuracy might be improved even further by repeated practice with the same words, a redesign of troublesome letters and a determination of the optimum dimensions for tactually presented characters. Other avenues of possible future research were also pointed out.

§ 1. Introduction

There are many practical situations where it would be desirable to impart information by the sense of touch, for example during military night-combat operations where light or sound might reveal position. Though the need for basic information concerning the ability to communicate by touch has been generally recognized, the literature reveals only very preliminary information, and this is concerned only with the accuracy of identifying single letters, numbers, and simple geometric figures. The present study is concerned with determining the accuracy and speed with which words of varying length can be read tactually.

The pioneering study in this area was by Austin and Sleight (1952 a). They used characters cut from $\frac{1}{4}$ in. masonite sheeting which were the maximum size that could be inscribed in a $\frac{1}{2}$ in. circle. Two forms of presentation were employed: in one the outlines of the figures were solid; in the other they consisted of a series of points, 2 mm apart. The former proved the easier to discriminate when the subject was allowed to move his index finger freely over the figures. Under this condition, 25 of the 43 figures studied were discriminated accurately on 90 per cent or more occasions.

In a subsequent study Austin and Sleight (1952 b) investigated several factors relating to the speed and accuracy of tactual discrimination. They found that a great deal of learning took place during a short training session, as shown by a marked increase in accuracy and decrease in reaction time. They also discovered that there were no significant differences between discriminations made by left- and right-handed subjects, between men and women, or between any of the four right-hand fingers (thumb excluded).

The present study is an extension of the work of Austin and Sleight to the discrimination of entire words. It seemed safe to assume that the tactual identification of any word is not merely a summation of the accuracy and time

characteristics associated with each of the letters comprising the word. Accordingly, the accuracy and speed of identifying words of varying length were investigated. The extent to which practice improves tactual performance was also noted.

§ 2. Procedure

There were six subjects, three men and three women, all between the ages of 20 and 30 years.

Figure 1. The letters used (half-scale). The original height was 0·68 in. and the stroke width 0·12 in.

Two complete sets of letters were made from $\frac{1}{4}$ in. brass sheet metal. The characters, which are shown in Fig. 1, are known as AMEL letters (Brown 1953) and are one of the generally recommended styles for military applications involving visual displays. The dimensions selected were well above the threshold values employed by Austin and Sleight.

The letters were fixed in position to form a word by pressing them slightly into a $\frac{1}{4}$ in. layer of clay on a metal plate. They thus were kept in place during a test but could be removed easily to form a new word once the test had been completed.

The following 90 test words were constructed from these letters :

Group A

IF	ALL	FALL	SMELL	BOTTOM	GENERAL
TO	RED	BURN	WHITE	FINISH	COMFORT
HE	FIT	TEAR	SPILL	STRING	PROBLEM
DO	SKY	SEND	TRICK	ATTACH	AVERAGE
OR	WAR	TURN	RAISE	REMOVE	DISPLAY

Group B

UP	ARM	STOP	FIRST	GROUND	SURFACE
ON	SET	FIRE	START	ROCKET	CONTROL
IN	TOP	FUZE	SIGHT	ATTACK	MESSAGE
GO	KEY	SAFE	BLACK	FOLLOW	SETTING
AT	OFF	DOWN	GREEN	SECOND	MACHINE

Group C

BE	MAN	VAST	QUICK	INSERT	REPLACE
AM	SAW	FROM	RADAR	RETURN	DESTROY
AN	PIN	LAND	VITAL	BEFORE	RETREAT
OF	YOU	COLD	SLOPE	URGENT	MISTAKE
SO	CAR	JEEP	TRAIN	TESTER	INSTALL

Two subjects were tested in each of the orders ABC, BCA and CAB, so as to distribute any serial effects such as those of practice and fatigue over all experimental conditions equally. The order of presentation of words within the three blocks of test words was kept the same in all cases.

Subjects were told the purpose of the experiment in general terms and were asked to work as rapidly and accurately as possible. They were shown the apparatus at the beginning of the experimental session and were then blindfolded. Two or three, but not more, words were given for practice before the test began. A rest period of five minutes was given after every fifteen test words. No restrictions were placed on the manner in which the fingers were used to make the discriminations.

The experimenter noted the accuracy with which the test words were read. Time was measured by stop-watch from the moment the subject's finger touched the letters to the verbal identification of the word. Also noted were the types of finger movement made, and the types of errors.

§ 3. Results

3.1. *Speed and Accuracy*

The times taken and errors made are set out in the table below. It will be seen that the time increased approximately linearly with length of word, and that the errors were very low.

Means and standard deviations of times to read words of different lengths, and numbers of errors.

Number of letters in word	Time per word in seconds Mean	SD	Errors in 90 trials
2	5·5	1·9	4
3	8·4	3·4	3
4	11·0	4·4	0
5	15·9	7·8	2
6	17·9	8·7	3
7	24·5	12·5	3

An analysis of incorrect responses revealed two types of error : those attributable to incorrect letter identifications and those due to incorrect

readings (perhaps anticipations) of the terminal portions of test words. The actual errors made were :

Test word	*Incorrect response*
HE	ME (twice)
AM	AN (twice)
CAR	CAP
WAR	MAR
SAW	SAM
QUICK	BUICK
SMELL	SMALL
REMOVE	RENOWN
INSERT	INSECT
ATTACK	ATTACH
AVERAGE	AVERAGING
MACHINE	MAKING
GENERAL	CENTRAL

Judging from comments made by subjects, unusually long times of response were attributable to two types of difficulty. The first concerned the distinguishing of individual letters, of which the most troublesome were said to be M, N, W, H, Q, K, G and S. The second was a matter of integrating the letters into a word. Examples of this type of difficulty were found with such words as RADAR and URGENT. In these cases the subject spelled out each letter correctly but did not recognize it as a word or forgot the initial portion of the word by the time he reached the final letters. This type of difficulty occurred more frequently with longer words as one would expect.

3.2. *Effects of Practice*

The mean time for all words in the first block presented was 16·6 sec. compared with 13·7 sec for all in the second block and 11·7 sec for all those in the third. There was thus a decrease of 17·5 per cent from the first to the second blocks and of 29 per cent from the first to the third.

Effects of practice in relation to length of word are shown in Fig. 2. Performance with two- to five-letter words appears to have levelled off after the first block. Improvement continues, however, between the second and third blocks for 6- and 7-letter words although the amount of it was not significant beyond the 10 per cent level.

3.3. *Effects of Familiarity*

It must be remembered that each subject was tested on 90 different words with no duplication of any word. The time scores obtained do not, therefore, reflect the effects of practice with repetitions of the same words. The data obtained are applicable to situations where the machine operator is called upon to operate some device with which he is entirely unfamiliar. Such instances would, however, be rare. Usually the operator would be entirely familiar with his apparatus and know what words he had to identify.

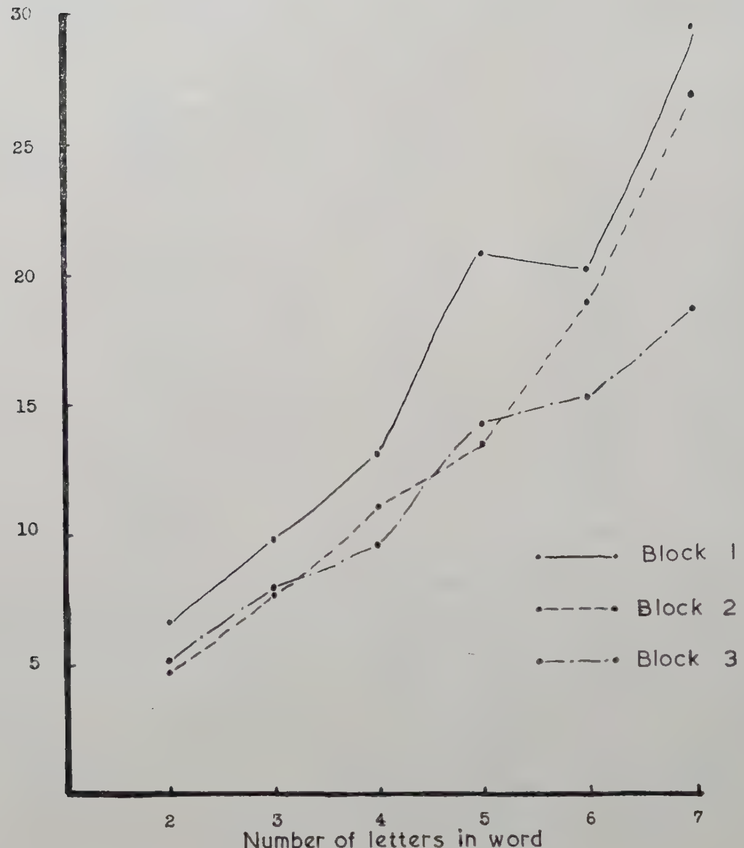

Figure 2. Effects of practice.

In order to obtain some indication of the effects of knowing the words to be identified, the experimenter was tested with Group C words. The average times taken were as follows :

Size of word (numbers of letters)	2	3	4	5	6	7
Mean time (in seconds)	4·0	7·0	9·4	9·0	8·8	11·2

A comparison of these results with those reported in the table on p. 64 suggests that familiarity with the words cuts down the required tactual discrimination time considerably.

§ 4. Further Research

As with most exploratory researches, this study raises more questions than it answers. Further research is, for example, needed to determine the optimum physical characteristics and letter forms for tactual stimuli. In addition, some attention should be given to the best spacing of letters. Still another question concerns the requirements for tactual stimuli which must be read with a gloved hand, since most military equipment requires an arctic capability.

L'étude constitue un essai de détermination de l'habileté individuelle à lire des mots en présentation tactile (lecture au tact). Ces renseignements ont des implications pratiques sur des situations militaires ou autres dans lesquelles l'opérateur d'une arme ou d'une machin eest appelé à desservir son matériel en absence d'indices visuels.

Six sujets ont effectué un total de 540 identifications de mots comprenant de deux à sept lettres. Le temps moyen de performance croît à peu prés linéairement de 5,5 sec. pour les mots à deux lettres, à 24,5 sec. pour ceux à sept lettres. Une séance d'entraînement d'une heure portant sur 90 mots a montré une diminution générale de 29% de la durée de lecture. On s'est également aperçu qu'un apprentissage répété avec les mêmes mots pourrait réduire davantage encore le temps de performance. En conclusion, on peut dire que le temps mis par un opérateur pour recevoir, par lecture au tact, ce type d'information rend possible l'emploi practique de cette technique dans la plupart des situations où les indices visuels seraient exclus.

L'exactitude des réponses était de 97,2%. Ce degré élevé de précision peut encore être accru par un entraînement répété avec les mêmes mots, par un meilleur tracé des lettres créatrices de confusion et par la détermination des dimensions optima des caractères présentés au tact. D'autres perspectives possibles de recherches sont aussi relevées.

Die Untersuchung, über die hier berichtet wird, war ein Versuch, die Fähigkeit von Personen zu prüfen. Worte durch Tasten zu lesen. Diese Art der Information hat praktische Bedeutung für militärische und andere Situationen, in denen Waffen oder Maschinen ohne optische Informationen zu steuern sind. 6 Personen identifizierten 540 Wörter von 2 . . . 7 Buchstaben. Die mittlere Zeit nahm nahezu linear von 5·5 sec für 2 Buchstaben bis 24.5 sec für 7 Buchstaben zu. Uebungen mit 90 Wörtern über eine Stunde verbesserten die Zeiten um 29%. Es zeigte sich auch, das wiederholte Uebungen mit dem gleichen Wort die Zeiten weiter verringerten. Es wird geschlossen, dass die für das Lesen von Wörtern mit dem Tastsinn benötigte Zeit für die meisten Situationen, in denen visuelle Information nicht möglich ist, ausreicht.

Die Genauigkeit der Antworten war 97·2%. Dieser hohe Genauigkeitsgrad liesse sich durch wiederholtes Ueben mit den gleichen Wörtern und durch Ersatz schwierig zu tastender Buchstaben und Wörter weiter verbessern. Andere Wege künftiger Untersuchungen werden herausgestellt.

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WARMTH, GLARE AND A BACKGROUND OF QUIET SPEECH: A COMPARISON OF THEIR EFFECTS ON PERFORMANCE

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In two experiments the effects of a high air temperature on the accuracy and manner of manual tracking were compared with those of quiet speech and of glare.

In each experiment 12 subjects attempted to keep a pointer aligned with a moving target for 40 min in both a normal and a warm climate, with instructions to be as accurate as possible. During the middle 20 min of each period of work the subjects in one experiment faced the glare from a naked electric lamp, and those in the other had a quietly spoken narrative relayed to them.

All three conditions reduced accuracy of alignment, but warmth affected the manner of tracking differently from quiet speech and glare. With the two latter conditions movements of the pointer decreased in number, i.e. errors of alignment were corrected less frequently. At a high air temperature the number of movements of the pointer increased, i.e. corrections were more frequent than usual. It was concluded that glare and a background of speech interfered with perception but that warmth affected chiefly accuracy of movement.

§ 1. INTRODUCTION

UNUSUALLY warm atmospheres have been shown repeatedly to cause a deterioration in the performance of a number of widely different tasks (Carpenter 1950, Mackworth 1950, Pepler 1958, Teichner and Wehrkamp 1954, Viteles and Smith 1946, Weiner and Hutchinson 1945). Little or nothing is known, however, of the mechanisms or causes underlying these effects. Changes in performance have been observed in the absence of (Watkins 1956, Weiner and Hutchinson 1945) or independently of (Mackworth 1950, Pepler 1958) changes in the concomitant physiological indices of an effect of warmth, such as body temperature, or the amount of weight lost as sweat. One has been left wondering whether the reported decrements in efficiency were in fact due to the level of warmth, or merely to the general strangeness of abnormality of the condition.

It was decided therefore to seek indirect evidence of the mechanisms responsible for performance changes in an unusually warm environment by comparing the nature of these effects with those of other abnormal background conditions. In two experiments the effects of warmth on the performance of an experimental task were compared with the effects of (1) the glare from a naked electric lamp and (2) a quietly spoken but interesting narrative.

§ 2. METHOD

The experimental task was a perceptually difficult form of pursuit-tracking. A pointer had to be kept aligned as accurately as possible with a target-mark, which moved erratically to and fro across a 4 in. aperture with a mean frequency of 0·5 c.p.s. The aperture was covered by a diffuser which reduced the visibility of the pointer and target to near threshold values. On the front of the

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apparatus just below the aperture, there was a small screened light which lit up whenever the pointer was misaligned by more than one centimetre. Subjects sat in front of the apparatus, and could move the pointer from side to side by raising and lowering a lever with their right hand.

Two aspects of performance were measured. The first was the error of alignment integrated over time by means of an electrical integrator. The second was the number of times the pointer reversed its direction of movement in excess of the number of reversals of movement of the target. Both scores were recorded on a panel outside the experimental chamber and were thus taken without interfering in any way with the subjects.

Tests of the statistical significance of the results were made by an analysis of variance technique. Since the means and ranges of homogeneous samples of these scores were positively associated, the analyses were carried out on the logarithmic transformations of the raw scores, recorded for each 10 min of the periods of continuous work.

Two temperature conditions were used. In the control or 'normal' condition the climatic chamber was maintained at an air temperature of 69°F (21°C), and a wet-bulb thermometer reading of 64°F (18°C). In the 'warm' condition the air temperature in the chamber was 100°F (38°C), with a wet-bulb reading of 90°F (32°C). The average air movement was 100 ft per min.

In Experiment 1, glare was produced by a naked 100 watt tungsten filament electric lamp, placed ten inches to the right of the target and pointer, i.e. 15–20 degrees to the right of the subject's centre of view. Target and pointer were not illuminated by the light from the glare source.

In Experiment 2, a background of quiet but interesting speech was provided by a tape recording of a woman's voice reading a descriptive passage from a thriller. The recording was played back over one earphone at such a low intensity that the speech was only just intelligible.

Twenty four physically fit sailors in the Royal Navy, between the ages of 18 and 25 years, volunteered to act as subjects with the promise of a small increase in pay and some additional leave. Twelve were used in each experiment. The subjects in Experiment 1 had done the tracking task for 40 min a day for the preceding five weeks. Those in Experiment 2 had had at least one week of practice for one hour a day at the task, before the experiment.

During practice and in test periods at a normal temperature the subjects wore their usual indoor uniforms, but in warm test periods they wore only cotton shorts.

The design and procedures of both experiments were the same. The air temperature at each day of the test week, for six subjects in each experiment, was 69°, 100°, 100°, 69°, 69°F. For the other subjects the temperatures at each test day were 100°, 69° 69°, 100°, 100°F. The results on the first day of the test week were not included in the analyses.

The subjects in both experiments did the tracking task continuously for 40 min daily. During the middle 20 min of each work period in Experiment 1 glare, and in Experiment 2 quiet speech, was 'switched on'. The subjects were instructed to keep the pointer aligned as accurately as possible with the target, they were warned that they would hear quiet speech, or face a bright light (as appropriate) for the middle 20 min, and they were asked to take no notice of it and to continue to track accurately.

§ 3. Results

3.1. *Experiment 1: Effects of Warmth and Glare*

Both glare and warmth increased alignment errors very significantly ($P < 0{\cdot}001$ in each case), but glare decreased ($P < 0{\cdot}05$), whereas warmth increased the number of pointer movements ($P < 0{\cdot}001$).

The effects of glare during the middle 20 min of the 40 min work periods are shown in Table 1. They were superimposed on two general fatigue or time effects—a progressive loss of accuracy ($P < 0{\cdot}01$), and a progressive decrease in number of pointer movements ($P < 0{\cdot}05$) over the periods of continuous work.

Table 1. The effects of a glare source on the accuracy and frequency of pointer movements during 40 min of continuous tracking (Experiment 1).

Scores	10 min samples				Standard deviation of difference between the two conditions for individual subjects
	1 (Control)	2 (Glare)	3 (Glare)	4 (Control)	
Log error	2·534	2·640	2·673	2·596	0·017
Log excess movements	2·070	2·014	1·974	2·018	0·030

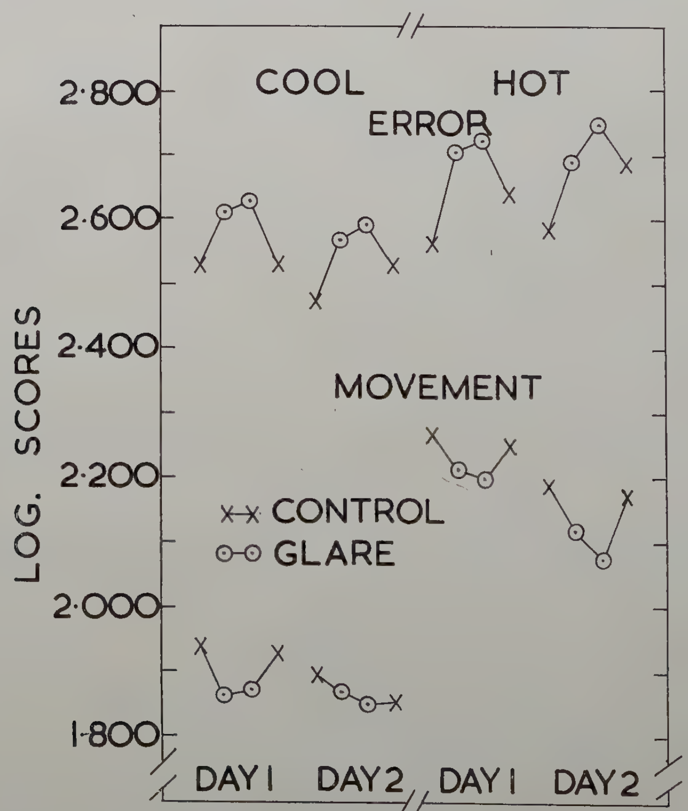

Figure 1. Effects of glare and warmth. Error scores (in arbitrary units) and numbers of movements made in excess of those required.

The effects of the glare were not significantly different at the two levels of warmth, nor on the two days at the same temperature (Fig. 2).

The decrease during the work period in the accuracy of alignment was, however, greater at the high than at the normal temperature ($P < 0{\cdot}01$), and on the second day at each temperature ($P < 0{\cdot}05$). But the average decrease in accuracy during work cannot be assessed independently of an effect of the glare and so the latter condition may have contributed to these effects.

3.2. *Experiment 2: Effects of Warmth and Quiet Speech*

In general, the background of quiet but interesting speech appeared to have a rather different effect on tracking than unusually warm surroundings. Both conditions tended to reduce accuracy in aligning pointer and target, but whereas the speech also reduced the number of movements of the pointer, there was some evidence that warmth increased it.

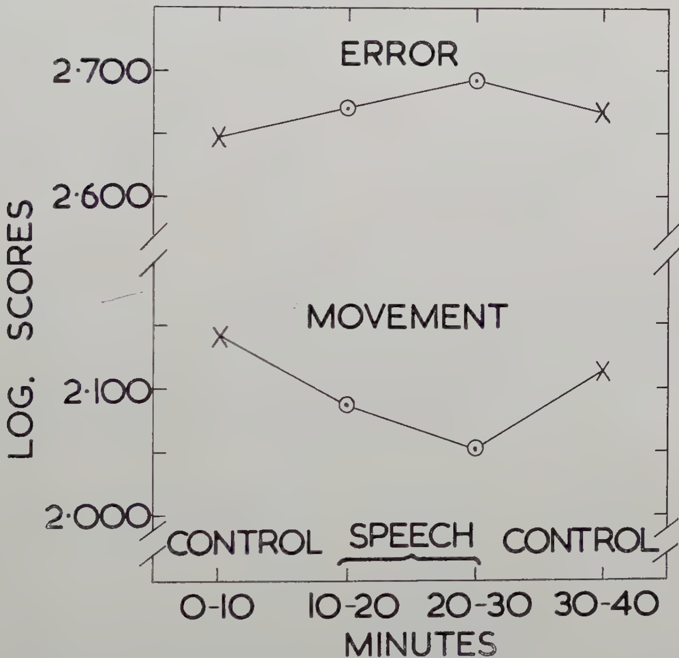

Figure 2. Effects of quiet speech and warmth. Error scores (in arbitrary units) and numbers of movements made in excess of those required.

The increase in errors and decrease in pointer movements which occurred with the quiet speech were both significant ($P < 0{\cdot}01$ and $< 0{\cdot}05$ respectively, Fig. 2). These effects were independent of the warmth of the atmosphere.

The nature of the effect of warmth was somewhat ambiguous because differences in score at the two levels of warmth were superimposed on other changes which were still occurring from day to day during the experiment. The preliminary week of intensive practice was insufficient to stabilise the performance of the task before the experiment. Further, the daily changes in score were influenced also by the different orders in which the two groups of six subjects experienced the two levels of warmth. In the analysis of the combined results of all the subjects the effects of warmth appear as significant

differences in the changes in error ($P = 0{\cdot}01$) and in movement ($P < 0{\cdot}05$) from the first day to the second at each air temperature (Table 2). Warmth seems to have halted a daily improvement in accuracy, and at first to have increased the movement of the pointer.

Table 2. The accuracy and frequency of pointer movements in tracking on two consecutive days at two levels of warmth (Experiment 2).

Scores	Cool {DB/WB 69°/64°F}		Hot {DB/WB 100°/90°F}		Standard deviation of difference between days for individual subjects
	Day 1	Day 2	Day 1	Day 2	
Log error	2·705	2·610	2·676	2·686	0·027
Log excess movements	2·021	2·058	2·259	2·049	0·069

§ 4. Discussion

Less efficient performance in warm environments might be due directly to the level of warmth, or to a distracting effect of the conditions. All abnormal conditions tend to distract in some degree, and may thereby accentuate those failures in attention which tend to develop during the prolonged performance of a task. Warmth, noise, and moderate sleep loss have all been shown to produce this effect on tasks requiring sustained attention (Broadbent 1953, Mackworth 1950, Wilkinson 1958, 1959). The present experiments appear to demonstrate that warmth may also have a more direct effect on the performance of manual tracking.

Movement of the pointer in excess of the movement of the target suggests that subjects in these experiments were making secondary or additional movements to correct inaccuracies in their primary tracking movements.

If subjects were less ready to notice or less able to see the inaccuracies of their tracking movements, they might be expected to make fewer corrections. This is what appears to have happened in the presence of quiet speech and in the face of glare from a naked electric lamp. Both of these conditions seem to have interfered with perception of alignment errors.

The increase in movement of the pointer which occurred in the warm conditions is suggestive of a different kind of interference. Perception of errors seems to have been unimpaired, attempts at accurate alignment were undiminished, but movements of the pointer appear to have been less accurate than usual, less well coordinated with the movement of the target. The results of these two experiments thus support the view that environmental warmth may reduce an individual's ability to execute accurately timed and graded movements.

Financial support from the British Medical Research Council and generous assistance for this research from the British Royal Navy are acknowledged most gratefully.

The writer is particularly indebted to the encouragement of Dr. N. H. Mackworth, whose helpful criticisms, and those of Dr. A. Carpenter, clarified much of this report. Miss V. Cane gave valuable statistical advice.

Dans le cours de deux expériences, les effets d'une temperature très elevée de l'air sur le genre et sur la précision d'un mouvement à main ont été comparés avec les effets d'une langue calme et d'une mélange. Dans chaque expérience il etait la tâche de 12 personnes de suivre l'index qui se mouva avec vitesse d'un côté à l'autre aussi exactement que possible. L'expérience avait lieu dans un climat normale ainsi que dans un climat chaud (38°c sec, 32°c humide) pendant une durée de 40 minutes. Au cours des 20 minutes du milieu de chaque période de travail, les sujets de l'expérience avait eu en face une lumière nue éléctrique, tandis que dans l'autre expérience ils écoutaient—au fond—une conte parlée d'une langue calme. Toutes les conditions de ces trois expériences réduisaient la précision des mouvements. L'interférence par suite de la langue ou d'une mélange corrigeaient les chemins de mouvements moins souvent. Une température très elevée de l'air augmentait le nombre des mouvements corrigeant de l'index. On a conclut que la mélange ainsi que " la langue au fond " dérangeaient la perception, mais que c'était la chaleur au premier lieu, qui réduisait la précision du mouvement.

In 2 Experimenten wurden die Wirkungen einer hohen Lufttemperatur auf die Art und Genauigkeit einer Folgebewegung mit der Hand mit den Wirkungen ruhigen Sprechens und einer Blendung verglichen. In jedem Experiment hatten 12 Personen mit einem Zeiger einer sich rasch wahllos hin- und herbewegenden Marke möglichst genau zu folgen. Der Versuch wurde in einem normalen und einem warmen Klima (38°c trocken, 32°c feucht) 40 Minuten lang durchgeführt. Während der mittleren 20 Minuten jeder Arbeitsperiode hatten die Versuchspersonen in einem Experiment eine nackte elektrische Birne im Gesichtsfeld, im anderen Experiment hörten sie eine im Hintergrund ruhig gesprochene Erzählung.

Alle 3 Versuchsbedingungen setzten die Genauigkeit der Folgebewegung herab. Bei der Störung durch Sprache oder Blendung wurden die Bewegungsfelder weniger häufig korrigiert. Bei hoher Lufttemperatur nahm die Zahl der Korrekturbewegungen des Zeigers zu. Es wurde geschlossen, dass Blendung und " Sprechen im Hintergrund " die Wahrnehmung störten, dass aber Wärme in erster Linie die Bewegungsgenauigkeit Revabsctzte.

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A PILOT JOB-STUDY OF AGE-RELATED CAUSES OF DIFFICULTY IN LIGHT ENGINEERING

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A pilot job-study was made of 853 machinists (mostly skilled) employed in a precision light-engineering shop. Fifteen factors were rated independently by two investigators. Subsequently, four factors relating to the environment and one relating to pacing were discarded because of lack of variation in this particular shop, as also were four relating to physical movement which required detailed measurement over a longer period. Of the six remaining, four appeared to be age-related (accuracy required, size of detail, kind of measuring instrument used and form of instructions) in the sense that the more difficult or severe the factor the younger were the individuals involved. Some tentative conclusions on the usefulness of this kind of study are given.

§ 1. Introduction

Studies of the relationship between age and job in the light engineering industry have suggested that some jobs are typically manned by men whose median age is below that of the industry as a whole (Murrell *et al.* 1957, Murrell and Griew 1958). In the main these jobs involve the skilled operation of metal working machines such as lathes or boring and grinding machines. It seemed that this result might be due to these jobs having some features which could be a source of difficulty to older men, thereby making them move away to other work towards the end of their working lives. Or, to put it in another way, the greater the apparent complexity of the job the more likely were young men to be engaged upon it. The present pilot job-study was undertaken in an attempt to identify some of the factors in the job situation which might be age-related.

It was clear from the outset that the usual methods of job analysis, job evaluation and so on would not serve the purpose in mind, so it was decided to adopt a simple method which seemed likely to show the lines which further studies might follow. In fact the study already reported by Griew and Tucker (1958) was developed directly from that being reported here.

§ 2. Method

The study was carried out in the machine shop of a firm engaged on small batch high-class production. In all, some 853 men were employed there; most were skilled men, but some drillers and profilers were classed as semi-skilled.

The analysis was carried out by the two authors, both of whom had worked for some years in industry (including engineering). Each worked independently and was accompanied throughout by a trainee charge-hand, each of whom was himself a skilled man. They advised on any points on which the investigators were in doubt.

The factors which were rated were divided into two sections (*a*) the environment, which comprised lighting, noise, heat and atmosphere; and (*b*) the

activity, which comprised lifting, applied force, body movement, speed of movement, accuracy of movement, touch, fineness of detail, discrimination, dial reading, nature of instructions and pacing.

The number of degrees into which each factor was split varied between three and five and depended on the extent to which it was thought to be possible to distinguish between one degree and another. It seemed unreasonable to adopt a rigid number of, say, four degrees when in one instance it would be impossible to distinguish more than three, while in another information would be lost when, say, five degrees were clearly definable. Each degree was defined and discussed between the investigators in order that both should have a common understanding of what was involved.

The main occupations which were studied are shown in Table 1 with their median ages.

Table 1. Median ages of workers in seven jobs

	Number	Median age
Borers	49	38·00
Capstan operators	47	29·80
Drillers	90	42·80
Grinders	234	37·50
Millers	237	35·44
Profilers	24	36·60
Turners	172	37·90

Median age of all shop-floor male employees in firm 42·73 ; in working population (1955) 42·02.

Within each main occupation there were a number of different activities depending on the type of machine being operated ; for instance, the method of operating a modern Genevois Borer differs from that for an older Kraus; there are a number of different types and sizes of pillar, multi-spindle or radial drills, while lathes vary widely in type and purpose. Each type of machine was rated separately and the age of the man working on it was noted. Similar machines engaged on similar work were taken together and the ages of their operators pooled. After the rating was completed the two investigators compared results; any ratings which were not agreed were discarded since it was felt that it was unsatisfactory to make changes retrospectively on the basis of memory.

§ 3. The Results

The environmental factors throughout the shop were found to be reasonably uniform, so no results were obtainable from section (*a*) which was discarded in its entirety.

Of the factors in section (*b*) it was found that the amount of lifting, force applied, body movement and speed of movement could not be assessed with any degree of certainty in the time available—detailed time-activity studies extending over several days would have been needed—and this formed the basis of the planning of the second job study carried out by Griew and Tucker.

These factors were, therefore, also discarded, as also was pacing, which was virtually non-existent in this particular shop. The six factors which were left were analysed in detail. These were:

(1) Accuracy. This was related to the tolerances to which the work had to be executed and was divided into four degrees. Very fine, less than 0·001 in. ; fine, about 0·001 in.–0·003 in. ; coarse, greater than 0·003 in.; and none. In the event it was found that the 'none' category was not required, so that this factor was reduced to three degrees.

(2) Touch. The extent to which an operator had to 'feel' the controls of his machine, as when a turner takes a cut by hand. Divided in three degrees, fine, e.g. the touch needed to take a finishing cut on a centre lathe or in grinding when hand operated ; coarse, e.g. the touch required for a rough cut or for drilling ; and none.

(3) Detail. The size of the detail of the piece being worked on. This could to an extent be determined from the drawings but no definite tolerances could be laid down as pieces varied so much. Divided into four degrees, very fine to coarse.

(4) Discrimination. The degree to which the operator had to use his skill to produce the desired result. Thus a part might have medium size detail but require very fine discrimination in turning a 0·003 in. radius at the junction of two surfaces at right angles to each other. Surface finish when grinding or honing, where it depends on the judgment of the operator, was rated under this heading. Four degrees, very fine, e.g. the finishing required in fine grinding or honing ; fine, e.g. the finish required in turning ; medium, e.g., quality required in semi-automatic work such as on capstans ; and coarse—no quality of finish demanded of the operator so long as he does not damage the tools.

(5) Dial Reading. Rated on three degrees—fine, accurate readings on a graduated scale such as a micrometer ; medium, readings requiring an accuracy of 1 per cent or less of full-scale value (this is the limit of accuracy proposed by the B.S.I. for an 'Industrial Instrument' such as a pressure gauge or ammeter) ; and none.

(6) Instructions. Five degrees. Very involved—drawings which required an appreciable amount of interpretation and/or calculation ; straightforward—drawings which could be followed with little interpretation or calculation ; simple written—telling the operator in writing what to do ; simple verbal—instructions given verbally ; routine—doing the same job repeatedly without fresh instructions.

Using these six factors, a table was constructed in which each cell represented the combination of one degree of one factor with one degree of another factor. Each cell contained the mean age of all men operating machines displaying the combination of degrees of factors associated in this way. For instance, in one cell the ages of men operating machines which required touch, degree 2, and discrimination, degree 3, were noted. Cells containing less than 20 men were discarded. The result is shown in Table 2. For ease of presentation degrees have been numbered from 1 up. 1 being the 'easiest' or simplest form of a factor.

Table 2

		Touch			Detail				Discrimination				Dials			Instructions				
		1	2	3	1	2	3	4	1	2	3	4	1	2	3	1	2	3	4	5
Accuracy	1	44·2	46·1	—	46·4	44·6	41·3	—	43·7	44·9	44·9	—	46·0	42·5	—	46·3	45·1	42·7	—	—
	2	—	40·5	39·1	—	41·2	39·3	—	—	40·7	39·6	—	—	—	—	—	—	40·7	38·6	39·3
	3	—	37·1	43·3	—	37·1	—	43·3	—	36·0	39·0	43·3	—	—	—	—	—	36·0	43·3	39·0
Touch	1	—	—	—	43·2	50·2	41·3	—	43·6	41·2	46·8	—	—	—	—	43·1	45·1	42·3	—	—
	2	—	—	—	49·3	40·7	41·4	—	43·6	42·5	40·0	—	46·6	43·1	39·7	46·6	—	39·5	—	39·2
	3	—	—	—	—	—	39·9	43·3	—	—	39·1	43·3	—	—	—	—	—	41·5	39·3	—
Detail	1	—	—	—	—	—	—	—	42·8	49·2	45·0	—	—	42·9	—	47·2	45·1	44·1	—	—
	2	—	—	—	—	—	—	—	44·2	39·6	41·3	—	43·7	44·3	39·4	43·7	—	40·6	—	39·2
	3	—	—	—	—	—	—	—	—	41·8	39·9	—	—	41·3	—	—	—	41·3	—	—
	4	—	—	—	—	—	—	—	—	—	—	43·3	—	—	—	—	—	—	—	—
Discrim-ination	1	—	—	—	—	—	—	—	—	—	—	—	—	43·6	—	44·0	45·1	42·3	45·5	—
	2	—	—	—	—	—	—	—	—	—	—	—	49·0	41·3	39·6	49·2	—	40·1	—	—
	3	—	—	—	—	—	—	—	—	—	—	—	—	44·9	39·3	—	—	42·5	37·8	39·2
	4	—	—	—	—	—	—	—	—	—	—	—	—	—	43·3	—	—	—	—	—
Dials	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	46·2	45·1	43·0	—	—
	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	42·5	—	—
	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	40·0	39·4	39·2

If we consider any pair of factors (e.g. dials 1 and 2 with accuracy 1 constant) our hypothesis would be that since degree 2 represents a greater contribution to complexity than does degree 1, then the age of men employed on jobs displaying degree 2 would be lower than that on degree 1—for dials 1 and 2 this is the case but in other instances the effect is reversed. It is thus possible to obtain a series of adjacent pairs, some of which support the hypothesis and some of which refute it. The hypothesis was tested by taking all the adjacent pairs relating to each factor and applying the Wilcoxon Signed-Ranks Test (T). The result is shown in Table 3.

Table 3. Application of Wilcoxon Signed-Ranks Test to data in Table 2

Factor	Pairs for	Pairs against	$T=$	P
Accuracy	12	2	19	$=0\cdot017$
Touch	6	7	—	NS
Detail	11	7	$51\cdot5$	$=0\cdot069$
Discrimination	12	11	$160\cdot5$	NS
Dials	9	1	2	$=0\cdot0047$
Instructions	14	6	57	$=60\cdot06$

Adjacent pairs only were used since it seemed possible that the differences between two non-adjacent pairs might be greater than would otherwise have been the case and this might have an undue influence on T. Actually, the only factor materially affected is ‘ instructions ’ and had non-adjacent pairs been included $P=0{\cdot}017$ instead of $P=0{\cdot}036$.

§ 4. Discussion

Having discarded, for various reasons, all the factors in the environment and those related to physical activity, six remained which might play some part in the complexity of a job. Of these, accuracy required, size of detail, dials and instructions are probably factors which may cause some difficulty to men as they get older. Touch and discrimination show no evidence of age relationship, and it is of interest to note that these are the two which depend most on the subjective judgment of investigators, the other four were to an extent derived from data.

Two conclusions can perhaps be drawn from this pilot study. First, that in job-studies of this kind useful results are more likely to accrue when, as in Griew and Tucker’s study, subjective assessments are kept to a minimum. It would seem that factors which require subjective assessment must, by their very nature, be somewhat nebulous in their concept and as such must be of doubtful value in any practical context. A pre-requisite to any worth-while assessment would be a more careful definition of the exact nature of a factor—by experiment if necessary—to reduce its components to measurable dimensions. For instance, the concept of ‘ touch ’ was rather woolly and, in spite of attempting to agree on a common understanding, neither of the investigators knew clearly all the parameters involved ; they might have included applied force, sound of the tool as it cuts, colour and size of the swarf, speed of movement of the part, and so on. It does not mean, therefore, that any of these factors may not make some contribution to age-related complexity, but

rather that the method used was not sufficiently sensitive to reveal any differences which might exist.

Secondly, there appear to be four factors which may play a part in job complexity and they are all factors which it might be possible to predict on theoretical grounds—' accuracy ' and ' size of detail ' might be influenced by changes in vision and perceptual-motor coordination, ' dial reading ' by ability to see fine engraved scales, by short-term memory and possibly by computing capacity, and ' instructions ' by ability to comprehend and translate and by short-term memory. The exact nature of these factors and the part played by various age changes are the subject of further experiments now being undertaken.

This study is part of a programme of research supported by the Nuffield Foundation.

On a mise à l'étude un examen du travail, les sujets étant 853 méchaniciens (dont la plupart étaient entrainés) qui travaillaient d'une façon méchanique à précision. Deux contrôleurs assignaient—l'un indépendent de l'autre—15 facteurs qui avaient l'effet de faire le procès plus difficile. Plus tard on a mise de côté 4 facteurs concernant le milieu du travail et un facteur qui avait quelquechose à faire avec la vitesse du travail, puisqu'ils ne montraient pas des variations suffisantes auprès des activités qui ont été l'objet de l'examination. Cela s'applique aussi aux 4 facteurs qui avaient une relation aux mouvements physiques et qui auriont été impossibles sans des mesures detaillées et prolonguées. Des 4 facteurs qui restaient, 4 semblaient d'être sujet à l'âge (précision acquéri, finesse des pièces, le genre des instruments à mesures et des instructions) : un plus grand nombre des jeunes travailleurs ont été engagé à mesure de la difficulté et de l'importance du facteur. L'utilité de ce genre de l'examination est estimée à titre d'essai.

Eine orientierende Arbeits-Untersuchung wurde an 853 Mechanikern (meist gelernten) durchgeführt, die in einer mechanischen Präzisionswerkstatt beschäftigt waren. Zwei Untersucher bewerteten—einer unabhängig vom andern—15 arbeits-erschwerende Faktoren. 4 Faktoren, die das Arbeitsmilieu betrafen und einer, der mit dem Arbeitstempo zu zun hatte, wurden später verworfen, weil sie nicht genügend Variationen bei den untersuchten Tätigkeiten zeigten. Das gilt auch für 4 Faktoren, die zur körperlichen Bewegung in Beziehung standen und nicht ohne lang-fortgesetzte detaillierte Messungen möglich gewesen wären. Von den 4 verbleibenden Faktoren schienen 4 altersabhängig zu sein (erworbene Genauigkeit, Feinheit der Stücke, Art des Messinstrumentes und Art der Instruktionen): je schwieriger und bedeutsamer der Faktor, desto mehr jüngere Arbeiter waren beschäftigt. Es wird die Nützlichkeit dieser Art von Untersuchungen versuchsweise eingeschätzt.

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THE DANISH NATIONAL INSTITUTE OF SOCIAL RESEARCH

Since the beginning of the 1940s, social research has been undertaken by the Danish Ministries of Labour and Social Affairs in order to provide data on social problems with a view to the preparation of new legislation, or to examine the effects of existing social legislation and administration. In some cases the initiative has been taken by the Ministries as such, but more frequently it has come from Government Committees asking for the examination of special problems in connection with their terms of reference.

The research has been mainly restricted to short-term problems in the fields of the Ministries of Labour and Social Affairs, and staff have been recruited and trained specifically for each study.

In March 1955, the Minister of Social Affairs appointed an expert Committee to consider how to develop a permanent organization for applied social research. The Committee laid down in its report the following basic principles:

(1) Continuity must be secured through a long-term research programme and the establishment of a permanent research staff who can profit by the experience obtained through successive research projects, and who are given opportunities to follow developments in social policy and social science.

(2) Within reasonable economic limits it must be possible to meet demands for the investigation of problems of immediate interest presented by public and private institutions, as well as of problems with a wider and longer perspective.

(3) A close collaboration must be established among representatives of the various branches of science required to deal with any particular problem.

(4) The aim must be to create a type of organization which has, on the one hand, continuous contacts with institutions dealing with social questions in practical ways, and, on the other, the freedom to research and publish its findings which is essential to scientific work.

The Committee proposed the creation of an independent National Institute of Social Research. The Danish Parliament followed this proposal and passed the necessary Act of Establishment on 18 April 1958.

Scope and Organization of the Institute's Activities

According to the Act, the Institute is administratively an independent institution under the Ministry of Social Affairs, but will be able to serve other branches of the administration and public and private organizations which are interested in social research. It will deal primarily with social assistance and insurance, labour problems, the social problems of family and youth and of housing and health conditions.

The Institute can permit independent scientists working in subjects falling within its field of competence to utilise its technical facilities, can transfer research work or parts of such work to other research institutions and share in meeting the expenses of such work. It is also available for the practical training of University students.

In the planning of its research, the Institute endeavours to keep in contact with similar work in other countries, and is interested in taking part in international research.

The Institute is governed by a Research Board and a Director. The former consists of representatives from the scientific disciplines which contribute to applied social research, and from those branches of administration which are particularly interested in the Institute. The Board approves the working programme and initiates research work. The Director has scientific and administrative responsibility for the Institute.

Staff is recruited from several disciplines, including economics, statistics, psychology, sociology and medicine. In September 1959 the academic staff numbered 14, of which 8 were full-time.

Funds are provided through the annual Government budgets. For the financial year 1959–60 the sum granted was 6 000 000 kr. For special projects funds may be obtained from other sources, such as private organizations and Danish or foreign foundations.

Research Projects

The Institute began its research work early in 1959 with the following programme of studies:

(1) *Consequences of the reduction of the working week*

Hours were reduced from 48 to 45 in a number of trades from 1 March 1959. The purpose of the study is to throw light on the direct and indirect consequences of this reduction for productivity and human relations. Special interest is focused on different ways of reducing hours of work, such as by week-end closure as compared with a shorter working-day.

(2) *Social and physical effects of shift work*

In the years 1950–54 the Directorate of Labour Inspection carried out an investigation on this subject collecting material from industrial firms working three shifts. This material which is as yet only partly analysed has been handed over to the Institute for final study. These studies will be widened to include also the effects of shift-work in the Police.

(3) *Estimation of the numbers of physically handicapped persons*

An investigation covering the whole country is being planned by the Institute at the initiative of various Danish societies for the prevention of disease and associations of disabled persons. The purpose of this investigation is to make a reliable estimate of the number of persons between 15 and 60 who are physically handicapped and of their composition according to diagnosis, sex, age, education, profession, income, housing condition etc. It is also hoped to throw light on the effectiveness of existing rehabilitation services, and the needs of different groups for further assistance.

(4) *The rôle of economic security and social welfare measures in the Danish population.*

A survey will be carried out, parallel with the study of the handicapped, to obtain information on the extent to which people prepare against economic risks including protection against loss of income in old age, sickness, unemployment and loss of the breadwinner from the family.

It is intended to study reasons why existing welfare and social services are sometimes not used, and to analyse popular opinion on social security.

(5) *The long-standing unemployed*

The Government Labour Market Council has requested the Institute of Social Research and the Directorate of Unemployment to embark upon investigations of the reasons for long unemployment and the possibilities for rehabilitation. The Institute is studying the possibilities of an investigation in this field.

(6) *Social gerontology*

This subject has high priority on the research programme of the Institute. Initially, the collection of all existing Danish statistics regarding the living conditions of the elderly is being undertaken and will be published.

The Government Statistical Department has recently undertaken budget studies of old-age pensioners; and as a part of its morbidity study the Board of Health has collected material on health and living conditions of the elderly. The basic material from these investigations has been handed over to the Institute for further examination.

(7) *Economic and social data*

For use in sampling procedures, the Institute has collected information on the economic and social structure of all Danish local communities. This has been collected from published statistics and from unpublished material in the Statistical Department and will be published as a handbook.

LETTER TO THE EDITOR

Dear Sir,

Research Information

Once a year the Research Information Committee of the American Institute of Industrial Engineers requests that research sources submit research performed in the area of Industrial Engineering. Information is solicited from universities, industrial organizations, research institutions, and non-profit organizations, including government agencies and professional societies. Abstracts of research are published annually and provide a valuable service to both industry and universities. Abstracts are collected in the areas of:

Work Measurement
Methods
Plant Engineering
Human Engineering
Engineering Economics
Organization Planning
Industrial Statistics
Production Control
Data Processing
Operations Research
Cost Analysis
Industrial Engineering Education

The committee will appreciate all information on past and present research in these areas, about which it might gather abstracts.

Yours faithfully,
Jay Goldman, *Chairman.*

Research Information Committee, AIIE,
Department of Industrial Engineering,
Washington University,
St. Louis 5, Mo., U.S.A.

INTERNATIONAL ERGONOMICS ASSOCIATION
STOCKHOLM CONFERENCE 1961

THE Association plans to hold its first Congress from 20–23 August 1961 in Stockholm at the Royal Institute of Technology and the Royal Central Gymnastics Institute.

The programme will include symposia on a number of topics with invited speakers, and also individual papers. Visits to factories and laboratories in Stockholm and neighbouring districts may also be arranged. The Congress will not be divided into sections on a disciplinary basis, and all participants will therefore be able to follow all papers. It is hoped in this way to foster the bringing together of specialists from various disciplines in joint discussion. For economic reasons there will be no translation and all communications will be in English.

Arrangements are in the hands of a local committee consisting of

Professor S. Forssman (*Chairman*),
Professor E. Hohwu Christensen,
Professor B. Ingelmark,
Professor G. Johansson,
Dr. N. Lundgren,
Mr. L. Rask,
Dr. A. Yllo.

The accommodation available is inevitably limited, and in order to assist the local organisers in their plans those hoping to attend are asked to get in touch with Mr. T. Olson, Department of Industrial Physiology, G.C.I., Lidingövägen 1, Stockholm Ö before 1 April 1961. Mr. Olson will also be glad to answer any further questions about the Congress.

Further information about the programme and detailed arrangements will be circulated to enquirers as soon as possible.

ERGONOMICS RESEARCH SOCIETY

PROCEEDINGS

A meeting on the physiological and psychological aspects of athletics was held in conjunction with the Central Council for Physical Recreation "*ad hoc* group on training and fitness" at the London School of Hygiene on Friday, 19th June, 1959. Dr. Graham Grant of the Welsh National School of Medicine was in the Chair for the morning session, which summarized investigations carried out on athletes participating in the 1958 British Commonwealth Games at Cardiff. The proceedings continued in the afternoon, under the Chairmanship of Dr. O. G. Edholm, M.R.C. Division of Human Physiology and ended with discussion. The following summary of the papers was prepared by Dr. J. E. Cotes.

(1) "The Athlete as a Research Subject", by J. E. Cotes, Medical Research Council Pneumoconiosis Research Unit, Llandough, Penarth, Glamorganshire.

Top class amateur athletes already have many demands made upon their time: they should not be asked to act as experimental subjects except in investigations for which they are indispensable. These will include both fundamental studies and applied investigations which have the object of improving some aspect of performance.

(*a*) Amongst the former we need to know more of the attributes of the athlete in terms of anatomy, physiology and psychology. What are the effects, for example, on athletic potential of size and body proportions? Are such variations confined to the gross anatomy such as the length of limbs, or are there also variations in microanatomy? In the case of the lungs, is the area of contact between the blood and the gas in the alveolar capillaries increased to facilitate the uptake of oxygen? Do athletes have distinguishing psychological characteristics? The answers to such questions may enable us to define the requirements for top performance, and the contribution of heredity, previous experience and training in their acquisition.

(*b*) The dynamics of maximum performance. What is the maximum output of the human machine in different situations? How is this achieved? What are the stresses which are thrown on the individual systems of the body, the heart, circulation, kidneys, musculature and so on? What are the factors limiting performance? These questions do not concern top-class athletes exclusively but their help is needed because few other subjects are prepared to push themselves to the same degree of physical exhaustion. The answers will be of value both to the physiologist in assessing the nature and long-term consequences of the stresses to which the athlete exposes himself, and to the physician in considering the ability of the several systems and organs in the body to sustain a comparable load in disease. In addition they will enable us to determine whether a high degree of cardiovascular efficiency and muscle development confers on the subject any advantage, either in activities for which he has no special skill or in relation to health and resistance to disease now or later in life. The subsequent history of athletes in relation, to artherosclerosis and, in women to gynaecological disorders, are obvious examples.

(*c*) The ergonomics of athletics. Problems of selection and training, the analysis and acquisition of skills, the prevention of accidents, with which we might include warm-up, and adaptation to the environment of the athletic events, are all legitimate subjects for investigation.

(*d*) Pitfalls. The investigator has an obligation both to his subjects and to others who may succeed him. He needs at the outset to realize the nuisance he may be causing through discomfort, psychological disturbance or derangement of the athlete's training programme. He needs to explain and justify his proposed investigation and to assess inpartially its possible application. He must not abuse the confidence of his subject by making unnecessary measurements—ones which could have been made on more average subjects. He needs to be aware lest he competes with other investigators for subjects or inflates the importance of his own investigation at the expense of those of others. Finally he needs to scrutinize his procedures since many which are acceptable in hospital or a laboratory may not be equally acceptable elsewhere.

In concluding the speaker mentioned investigations in which he was personally concerned. First, pulmonary diffusing capacity: working with Drs. R. S. Jones and R. G. Bannister, he had found a greater diffusing capacity in athletes than in non-athletes of the same age and

body size. This finding might be interpreted as evidence that athletes do differ from non-athletes in the microanatomy of their lungs. Second the dynamics of walking: in conjunction with the Misses J. Drummond and C. E. Yandle he had evidence that physical fitness was not an important factor leading to economy of energy expenditure in men. On the other hand, women athletes were able to walk more efficiently than non-athletes at high walking speeds.

(2) " Human Structure and Performance " by J. M. Tanner, Institute of Child Health, Hospital for Sick Children, London.

The speaker, who emphasized that his work was still in a very preliminary state, due in part to the difficulties of obtaining subjects, discussed two problems in particular. First, does structure become a selective factor for top-class athletes and, second, is structure related to the event in which the athlete competes? To answer these questions Dr. Tanner recorded for 237 male athletes both the somatotype, using a modification of the Sheldon photographic technique, and bone and muscle thickness by direct whole body radiography technique. The gonads were protected by a specially designed screen. Using this technique, no allowance could be made for the contribution of body fat to the recorded muscle thickness, but this was not thought to affect the findings. In general the somatotype and the muscle distribution in the different classes of athlete were those to be anticipated on the basis of previous work but it was evident that some types of training could lead to a big increase in muscle size in relation to bone structure. Thus whereas weight-lifters were inclined to have in their calves the same muscle/bone ratio as sprinters, who are of similar somatotype, the muscle width in their arms was very much greater. Bone thickness was found to vary less than might have been anticipated. Thus there were no differences in the ratio of bone cortex to medullary width between the sprinters and middle-distance runners. The speaker concluded that whilst structure will lead to self-selection for particular events, training will produce marked effects, especially when begun young: " athletes are born but they have to be made if they are to achieve top levels of performance ". The results of further studies along these lines should yield useful information.

(3) " Aspects of Circulatory Function " by F. Beswick and R. C. Jordan, Institute of Physiology, Welsh National School of Medicine, Cardiff.

Dr. Beswick, who presented this paper, referred to the importance of investigations on animals for a proper understanding of the relevant factors (e.g. Rushmer, R. F. and Smith O. A., *Physiol. Rev.*, 1959, **39,** 41). There were relatively few studies on athletes: one of the most ambitious was by Freeman *et al.* (*J. appl. Physiol.*, 1955, **8,** 37) who measured cardiac output and pulmonary artery pressures in three runners before and after training. The present authors recorded the resting electrocardiogram using carefully chosen chest leads to make a three dimensional vector-analysis of the distribution of potentials. Their findings on broad groups of athletes were compared with those on college students. They confirmed the findings of Bramwell and Ellis (*Arbeitsphysiol.*, 1929, **2,** 51) that athletes can be subdivided according to their resting pulse rates, long distance runners having the lowest values. The vector-analysis showed forward displacement of the Q.R.S. forces and lengthening of the ST interval during recovery from exercise in the athletes when compared with college students. These studies are still in progress and their further amplification should be of great interest in assessing the nature of the load which is imposed upon the heart during maximal exertion.

(4) " Heart Rates in Athletes after Moderate Exercise " by J. G. Fletcher, Division of Human Physiology, National Institute for Medical Research, Holly Hill, Hampstead, London*.

Dr. Fletcher, whose paper was read in his absence, made measurements of the pulse recovery rate in groups of athletes studied after a standard step test. This consisted of an initial half minute warm-up period of stepping on and off a 22 in. block at the rate of 30 steps a minute. The subject was then allowed to recover for $5\frac{1}{2}$ min before the 1 min period of test exercise, after which the pulse rate was followed for as long as necessary. Day-to-day variations were found within the subjects in association with variations in their performance, but most of the variability was between different classes of performers. The variation affected both the rate obtained immediately after exercise, the slope of the recovery curve, and the final plateau to which this descended. The pulse rate during the early recovery period was high in weight-lifters and sprinters and low in long-distance runners with quarter, half and one milers intermediate. These findings suggested that the degree of endurance

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required by the contestants was of greater importance than muscle strength in determining the cardiovascular response. Swimmers showed up well with a rapid initial drop in pulse rate. This was followed by a rise of as much as 10 beats/minute, the cause of which was unknown but might be related to factors enabling them to breathhold during exercise. Boxers, although they perform much long-distance running, did not resemble the distance runners in their responses. They had, however, a relatively low heart rate immediately after stepping. Differences between men and women appeared to be related to their training schedules: where these differed, as between men and women hurdlers, the pulse recovery rates varied appropriately but when they adopted the same schedules, as did the men and women jumpers and javelin throwers, the recovery rates were also similar. Herb Elliott, holder of the world record for the mile, had an outstandingly low heart rate which quickly fell to its initial value after exercise. Dr. Fletcher believed that the test could be usefully carried out to estimate the endurance of any selected athlete in comparison with others of his class and to check progress and guide training; being a relatively short sub-maximal test it also had the advantage of acceptability.

(5) " Human Power Output. The Mechanics of Pole-Vaulting ", by H. E. Lewis and D. R. Wilkie, Division of Human Physiology, National Institute for Medical Research, Holly Hill, Hampstead, London and University College, London.

The paper is printed in full in this issue, pp. 30–34.

(6) " Investigation by Questionnaire ", by H. E. Robson, Loughborough Training College, Loughborough, Leicestershire.

Dr. Robson, who was assisted by six students of physical education, described his experience in obtaining answers from athletes to a group of standard questions. The athletes corresponded, so far as possible, to those investigated by Drs. Tanner and Fletcher in order to obtain a more complete picture of these individuals. A wide variety of topics were chosen, including questions on warm-up, the use of weight training and the subject's general background and education, as well as a number of more medical questions which were put by the author himself. Preliminary experience of the method suggested that when properly controlled and carried out, much could be learnt both of the characteristics associated with different events and of the areas in which future applied investigations might be concentrated. The author hoped to carry out further investigations along these lines at the Olympic Games. In subsequent discussion the hope was expressed that he would use the intervening period to investigate observer error inherent in completing his questionnaires, including the effect on the answers of the way in which the questions were put; also of relating his own questions to those of others who have preceded him in the application of this powerful tool of investigation.

(7) " An Experimental Psychologist Looks at Athletics ". K. W. Blyth, Psychology Laboratory, Cambridge.

Mr. Blyth began with some disarming remarks on the difficulty of investigating the so-called psychological factors in athletics. They are often such that the psychologist has no advantage over the layman in speaking about them. He contrasted the position 30 years ago when, for example, an article in the *British Journal of Psychology* on the Psychology of Rowing could make the points that psychological factors such as mental attitude were of equal or greater importance than strength or muscular skill, and that an oarsman's style and work was greatly influenced often unconsciously, by auto-suggestion. The experimental psychologists today hope to approach these psychological factors indirectly. For the present he is more interested in how the nervous system functions, considered as a machine which takes in information, stores it, and translates it into action which is modified in a number of ways. This approach comes nearest to athletics in the consideration of skilled performance such as is discussed by A. T. Welford in recent numbers of the *A.A.A. Coaching Newsletter* (Nos. 10 and 11, 1959). Here he stressed the corrective as well as incentive effect of knowledge of results, the need to direct the man's attention to means of getting such knowledge for himself, and the importance of ensuring, by informal practice and training for flexibility, that initial reactions do not become fixed. Training fatigue is an allied problem. This can be successfully treated by rest, which must, however, be appropriate. It is not appropriate if during the rest period the subject is required to watch someone else performing the same task. Investigation of the waking and sleeping centres of the brain and of the effects of temporary deprivation of stimulation, are other subjects which may ultimately be important. Greater use might be made of questionnaires, but it is important to tackle problems which are capable of answer. For example, on the tactics of racing, the qualities necessary for success in athletics in competition as opposed to practice and the effect of athletics and other sport

upon character. The speaker warned his audience not to expect too much of psychologists: after referring to Frank Read's search " for words and methods that will coordinate the work of all boys in the crew ", he concluded that psychology can to some extent help with methods but the coach will always be searching for words. The art of coaching remains an art.

(8) " Changes in Urinary Composition Following Severe Muscular Exercise ", by P. E. Parry and R. A. Saunders, Department of Clinical Pathology, Llandough Hospital, Penarth, Glamorganshire.

In this paper, which was summarized in the authors' absence, a search was made for evidence of muscle breakdown in increased urinary excretion of amino acids. These were estimated by paper chromotography in urine specimens collected before and after 10 and 20 mile training runs in long-distance runners. Rather surprisingly no differences were found, but possibly the exercise, whilst prolonged, was not sufficiently intense. Urinary sodium showed a significant drop after exercise and the creatine-creatinine ratio was increased in two of the three athletes who ran the greater distance.

(9) " Short Term Adaptation to Heat ", by Dr. R. H. Fox, Human Physiology Division, National Institute of Medical Research, Holly Hill, Hampstead, London.

After a concise account of man's thermal exchanges and adaptive responses on entering hot climate, the speaker presented, by courtesy of the Air Ministry, a table of the temperature conditions likely to be met in Rome during August; he used these as a basis for a hypothetical calculation of their possible effects upon a marathon runner. He assumed a dry bulb temperature of 85°F, wet bulb 69°, globe thermometer 95°F, air speeds 10 m.p.h., and an energy expenditure of the order of 1000 kcal per hour for $2\frac{1}{2}$ hours. Under these conditions much heat needs be lost by sweating if thermal equilibrium is to be maintained. The actual amount depends on the skin temperature about which little is known. The total amount is likely to be of the order of 4 or 5 litres of sweat, which would be possible for a fully heat-acclimatized subject, though probably not for one who is unacclimatized. This amount of sweat can be evaporated off the skin whilst the subject is moving. As soon as he stops, however, the air speed falls and the maximum evaporative capacity is drastically reduced. This sudden reduction in heat eliminating ability may well be a factor in precipitating collapse with circulatory failure at the end of a long race. The rate of fluid loss requires a greatly increased fluid intake, both before and during the race, but the times when this can best be administered have still to be discovered.

(10) " Body Temperature and Performance ", by R. G. Bannister, National Hospital for Nervous Diseases, London.

Since early times runners have complained about the climate but less work had been done on the subject than its importance appeared to warrant. Studies by M. Nielsen (*Skand. Arch. Physiol.*, 1938, **79**, 193–230) suggested that the rise in body temperature during exercise was unrelated to the environmental temperature. Robinson, studying runners at very high levels of energy expenditure, found that their body temperatures were, in fact, higher at an ambient temperature of 29°C than at 5–15°C, rectal temperatures of 105·8°F and 106°F being recorded. These high temperatures apparently had no influence upon performance, but the subjects were acclimatized to the hot American summer. Comparable experiments were carried out on two British athletes and one from Kenya at Cardiff (Bannister, R. G. and Cotes J. E., *J. Physiol.*, 1959, **147**, 60P). These studies confirmed that the body temperature for a given level of energy expenditure rose to a greater extent at a room temperature of 25° than at 15°C in these subjects who were not well heat acclimatized at the time. Unlike the American runners, however, the performance of these athletes was adversely affected. The speaker concluded that the high arena temperature (25°C) during the 6-mile event at Cardiff contributed to the relatively poor performance of the British contestants.

This paper, and the preceding one, emphasized the need to make proper allowance for heat acclimatization in preparation for the 1960 Olympic Games at Rome, or for distance events to be run in the evenings, if British runners were not to be placed at a serious disadvantage.

(11) The final session, introduced by Dr. J. S. Weiner, Department of Human Anatomy, Oxford, was on research in athletics with the needs of the 1960 British Olympic Games Team at Rome particularly in mind. Dr. Weiner raised a number of points which evoked comment from the meeting. On temperature he suggested that athletes exposed to hot conditions should be given additional salt, approximately 8 to 10 g per day, and that psychogenic fever was a phenomenon which deserved more consideration. Dr. E. T. Renbourn (C.S.E.E.,

Ministry of Supply, Farnborough) described the rise in body temperature he had found in boy boxers prior to a contest and Dr. Tanner queried the calorigenic effects of adrenaline and noradrenaline. On the problem of access to athletes, Mr. K. S. Duncan (Secretary of the British Olympic Association) recommended that in Great Britain permission should be obtained from the A.A.A. and, where other nationals are concerned, adequate interpreters should be provided. Team Managers should then be approached and the instructions and requirements put in simple language which could be passed down from them through the coaches to the athletes. Tests should be carried out near the training camp and the results disseminated at all levels of participation so that all might feel that it was worth while. These points were taken up by a number of others, including Mr. John Disley and Mr. G. Elliott of the British Team, who felt that the object and nature of the investigations should be outlined in greater detail to the athletes and that they should be given some on-the-spot report of the findings. On tests of exercise performance, Dr. Weiner pointed out that sub-maximal tests such as that used by Fletcher are in general more acceptable, but that maximal tests may also be needed (Taylor, C., *Amer. J. Physiol.*, 1944, **142,** 200). Dr. W. F. Floyd (Middlesex Hospital Department of Physiology) suggested that the height of the step should be reduced as some subjects, in his experience, find a 22 in step uncomfortably high. Dr. Edholm commended standardized tests (e.g. Hugh-Jones, P. and Lambert, V. T., *Brit. med. J.*, 1952, **1,** 65). On the measurement of power output and its transformation there was a warm welcome for Dr. Lewis' report that the work was being extended to other events than pole vaulting, but disagreement at once arose on the appropriate occasions for such studies. Dr. Lewis considered that National Championships would be satisfactory but there was strong feeling that only the best was good enough: the vision of a British athlete clearing the bar at 15 ft as a result of such studies stirred the imagination of all. On psychological aspects, Dr. Weiner felt that in addition to assessments of athletic skill and personality there were practical problems such as sleeplessness prior to the event, the monotony of institutional life in the period immediately preceding the competition, and the demands of team managers which might merit investigation. Mr. Duncan mentioned that a psychologist accompanied an army riding team to Melbourne but no account has so far been published of his activities there. Mr. Blyth thought the problem of sleeplessness an important one and was intrigued by the idea of psychological trainers: he thought that on the whole it might be more interesting to investigate the trainer than the athletes. On the general problem of heat acclimatization there was no answer to Mr. Duncan's question " how soon before the Games should athletes go to Rome to achieve good acclimatization ?" Dr. Bannister was against pre-acclimatization in this country. Professor G. P. Crowden (Department of Applied Physiology, London School of Hygiene and Tropical Medicine) stressed the need for appropriate clothing and Mr. Duncan mentioned the possibilty that the preliminary full dress parade might have a deleterious effect upon subsequent performance. Air conditioning of the living huts with a view to getting a good night's sleep needed to be considered. On warm-up little information was available. Mr. A. R. Lind (Department of Human Anatomy, Oxford) outlined investigations which suggested that the muscle tension which could be developed was greatest when the muscle was at body temperature or above, but it was uncertain to what extent this was directly applicable to performance. Here was clearly a subject for further investigation. Training in breathing particularly in marathon runners, also came in for comment but there was general agreement with Mr. G. Dyson (A. A. A. National Coach) who felt it was best left to nature.

The meeting closed with the expressed hope that the proceedings would be a stimulus to further investigations and their subsequent dissemination amongst athletes.

J. E. Cotes.

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